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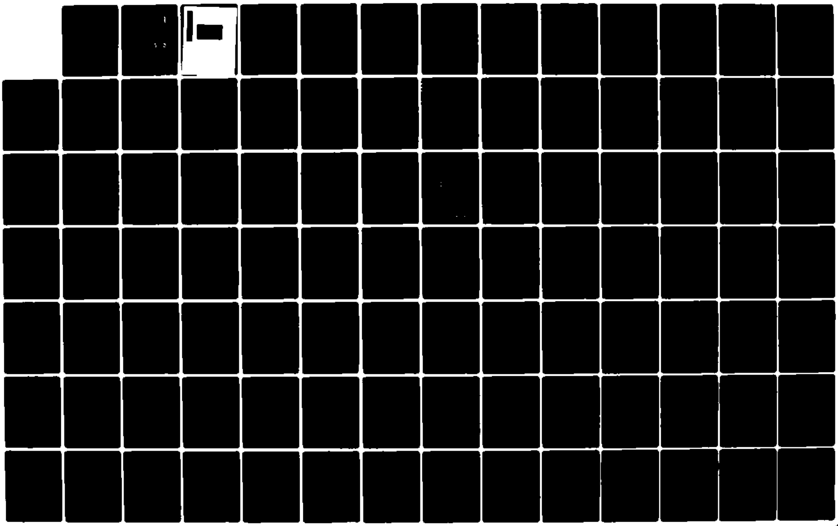

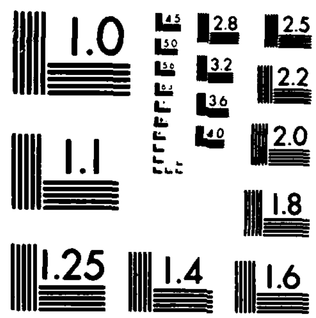

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Proposed Stockage Policies

for Recoverable Item Management

by

W. Steven Demmy

May 1980

TR-80-03

DECISION SYSTEMS
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Table of Contents

Section I

Introduction

This paper presents the results of a simulation study to evaluate the relative performance of 13 specific methods proposed for the management of Air Force recoverable items. An important feature of the study is the use of actual histories of Air Force recoverable item flows for F-15 and F-111 aircraft for the period FY74 through FY78. Using this data and a simulation model designed specifically for this study, we obtain answers to the question "How well would each of the proposed methods have performed had they been used during the FY74-78 interval?"

The paper has five major sections. In Section II we discuss the major features of the logistics system used to support the majority of AFLC recoverable items. The major mathematical models proposed for use in the management of this system are also discussed in Section II. In Section III, we discuss the types of data currently available for the development of a detailed model of Air Force recoverable item management systems. This chapter describes the data collection efforts undertaken to support this study, as well as the results of these efforts. In Section IV, we discuss the scenario which served as the basis of our simulation efforts. This section describes the computational policies which were evaluated, the materiel flows simulated in the RIME Evaluation Model, and the relationships among initial provisioning and replenishment calculations in the simulated system. Sections V and VI present the results of our simulation experiments. These sections present cost-effectiveness curves which compare the relative buy dollar and

backorder performance associated with each of the proposed policies. Section V discusses aggregate results, i.e., results obtained when simulation values were totalled across all items included in the simulation study. Section VI, on the other hand, presents separate cost-effectiveness curves for each of the LRU groups simulated. Finally, Section VII summarizes the results of our study.

Section II

Recoverable Item Materiel Flows

and

Associated Mathematical Models

Recoverable items represent an important sub-set of the total population of AFLC management items. This class includes items which may be repaired on failure and thus returned to a serviceable condition. Assemblies such as navigational computers, pumps, radio sets, and torque converters are examples of this class of items. Approximately 170,000 Federal Stock Numbers with inventories valued in excess of $5 billion fall into this category.

In general, recoverable items are supported by a two-echelon inventory/repair system such as that illustrated in Figure II-1. When a weapon system is first added to the Air Force inventory, initial provisioning includes procurement of a number of serviceable spares to support the new weapon. These spares are then dispersed to appropriate base locations to provide on-site support for operating forces. Usually, some serviceable spares are also maintained at a depot supply location. These depot stocks are used both to support depot repair activities, and to provide a backup source of supply for bases with unexpectedly high requirements.

When a recoverable item fails at base level, it is turned in to base supply and a new serviceable unit is issued. If possible, a failed item is then repaired by the base maintenance organization and returned to base supply. Sometimes, however, the failed item must be returned to the depot where more sophisticated equipment

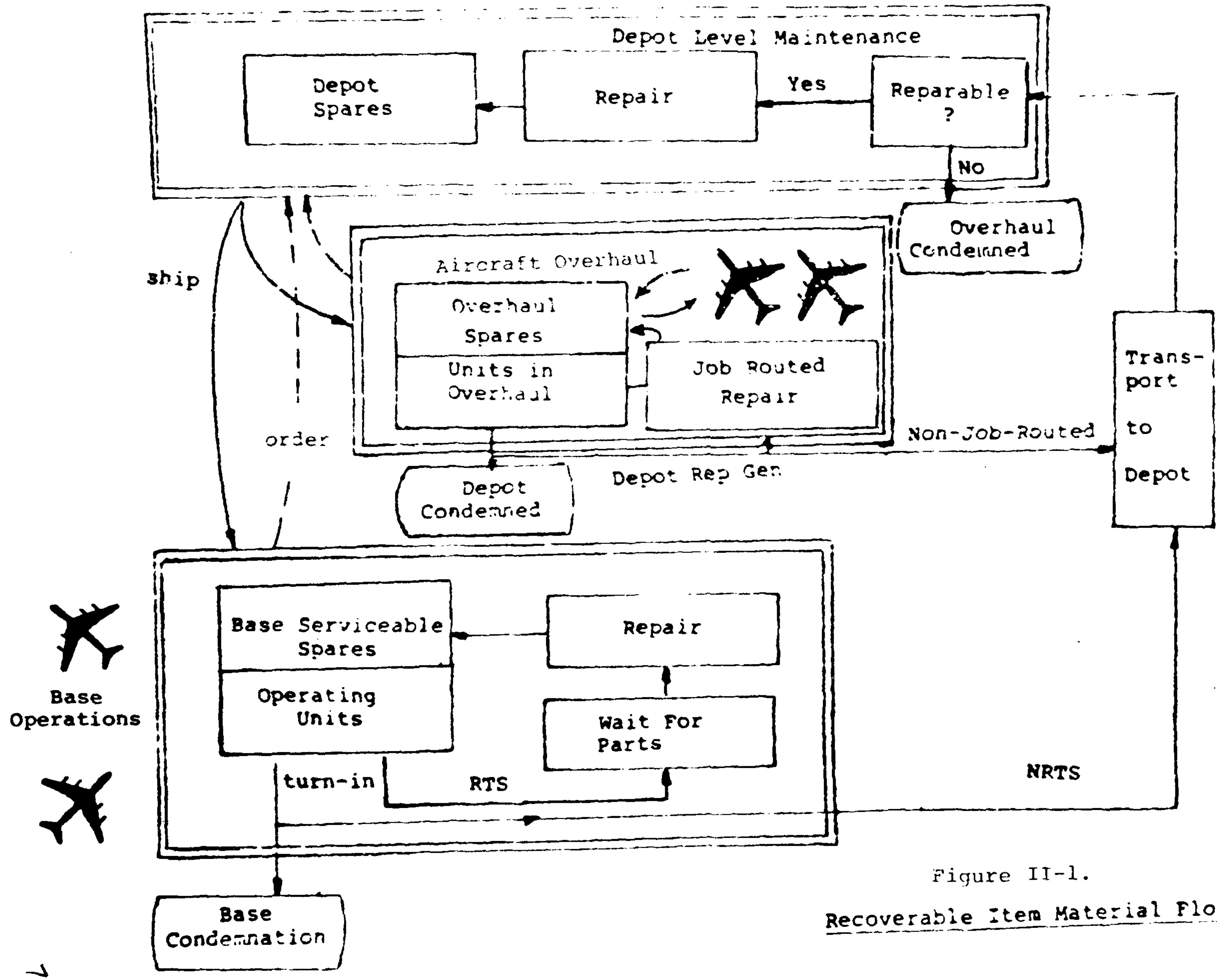

Figure II-1.

Recoverable Item Material Flows

7

and specialized skills are available. In this event, the base submits a requisition to the depot supply organization to obtain a serviceable replacement for the failed item. The depot in turn attempts to fill these requisitions. If serviceable units are available at the depot, the requisition is filled immediately. Otherwise the requisition is backordered until additional serviceable units are obtained from either the depot repair facility or from replenishment orders placed with outside vendors.

Occasionally, failed items cannot be economically repaired. In this case, the item is condemned, and the inventory system manager must then determine whether to order a replacement for the failed item, or to operate the system with one less spare asset.

As aircraft or other major end items age, it eventually becomes desireable to return the aircraft to an overhaul facility for major repairs and refurbishment. As a part of the overhaul process, certain components may be removed from the craft and replaced by serviceable units. The removed assets are in turn sent to appropriate repair facilities. We refer to such assets as "depot reparable generations", or "rep gens" for short. Hence, depot rep gens are another source of unserviceable assets.

LRU/SRU Relationships

The above discussion describes the materiel flows associated with a single federal stock number. In many instances, however, the materiel flows of different items may be closely related.

Many modern weapon systems are built on a modular basis. The term Line Replaceable Unit (LRU) is used to describe a major assembly that may be removed and replaced on an aircraft at the flight line. If a failed LRU cannot be repaired at

base level, the faulty unit would be forwarded to the depot. Otherwise, the LRU is moved to a base maintenance shop for repair. Repair of these modularly designed systems often consists of the removal and replacement of one or more of its components, or modules. These components of the LRU are called Shop Replaceable Units, or SRUs for short. Thus, SRUs represent a second level, or indenture, in the parts heirarchy of the aircraft. If the SRU cannot be repaired at the base, the failed SRU is either condemned or shipped to the depot. Otherwise, base maintenance personnel attempt to repair the SRU, perhaps by the removal and replacement of one of its components.

The activities of disassembly, removal and replacement continue until the faulty unit(s) is identified and corrected. Of course, similar activities also performed at the depot level to return failed LRUs and SRUs to a serviceable condition.

As in most real systems, there are a number of items which do not fit the pretty picture described above. At times, forward base locations will be supplied from another closely located base -- resulting in a three-echelon supply system for this item. For other items, a manufacturer may provide both a source of procurement for new assets as well as the source of repair for failed items. When tens of thousands of items are involved, there of course many other variations that can be observed. However, the above discussion appears to provide a good approximation to the logistics support system in existence for the majority of AFLC recoverable items.

Analytical Models of the AFLC Recoverable Item Flows.

Several mathematical models have been developed to assist in the management of AFLC recoverable items. Each of these models differ in terms of (a) the

underlying assumptions of the mathematical model, (b) the objective function to be optimized, (c) the mathematical optimization procedures used to find "optimal" solutions, and (d) computational shortcuts utilized to reduce the computational resources required to obtain solutions. Demmy and Presutti (1979) provide a detailed discussion of the analytical features of the major AFLC multi-echelon models. In this section, we provide only a qualitative discussion of these models. This discussion is presented to provide an overview of the policies to be evaluated later in this paper. The major models to be discussed include:

1. AFLC Regulation 57-27. This regulation describes the current procedure for initial provisioning of Air Force recoverable items.

2. METRIC. This is the acroymn for the "Multi-Echelon Technique for Recoverable Item Control", a two-echelon model originally developed by the RAND Corporation to determine base and depot stock levels for recoverable items. The term METRIC is used to describe both the original mathematical model and optimization technique, as well as the computer code which implements the method.

3. MOD-METRIC. An extension of the METRIC model which considers assembly/sub-assembly relationships.

4. The Variable Safety Level Computation (VSL). VSL is a modification of the RAND METRIC model which utilizes a different optimization procedure and which includes several computational shortcuts. The Variable Safety Level Computation is currently used to compute requirements for AFLC replenishment spares.

Let us now consider the major features of each of these models.

AFLCR 57-27.

Air Force Logistics Command Regulation 57-27 describes the rules to be used in the computation of initial requirements for expense, investment, and equipment items. Although the regulation does not explicitly state the underlying assumptions embedded in the computation, the regulation is essentially based on the assumption that all item parameters such as failure rates, base repair fractions, and condemnation rates are known with certainty, and that there is no variability of demand. The model then sets the initial provisioning requirement equal to the amount of stock required to fill the repair/resupply pipeline, that is, the amount of stock which has failed and is either in unserviceable condition and undergoing repair or which has been condemned and is in the process of being replaced by replenishment procurements. Figure II-2 presents a computation worksheet used in the application of AFLCR 57-27.

The METRIC Model.

As noted above, METRIC was orginally developed by Craig Sherbrooke (1968) of the RAND Corporation as a tool for managing Air Force recoverable item inventories. This model provides a methodology for computing stock levels in a two-echelon inventory/repair system consisting of a depot and possibly several bases. The objective of the model is to determine the base and depot stock levels which minimize total expected base level backorders summed across all items in the system subject to an investment constraint. By definition, a backorder exists at any point in time at which there is an unsatisfied demand at base level. If backorder- days are accumulated over a fixed length of time, the average daily number of backorders can be found by dividing the accumulated backorder-days by the number of days in the data period. METRIC seeks stock levels which minimize the mathematical expectation of this quantity. In METRIC, no penalty is directly

AFLCR 57-27

RECOVERABLE ITEM REQUIREMENTS COMPUTATION WORKSHEET (INITIAL-REPLENISHMENT)

PREPARING ACTIVITY | BUDGET CODE: BP 16 | DATE

I. ITEM DATA

1. NSN/NC & PART NO	2. Contractor & Registry Control No.	3. Noun	4. Contract Item Seq. No.
1620 00694 6580	Bendix 4372	Valve	376

5. End Article	6. QPA	7. Unit Price	8. U/I	9. ERRC	10.	11.	12.
B-1	1	$450.00	EA	XD2	—		—

13. Lead Time A. Admin	B. Prod	C. Proc	14. Repair Cycle A. Base	B. Depot (1) Days	(2) Mos	15. AFLC FORMS A. O&ST	B. AVG MO PROG (1) OIM	(2) DLM	C. S/L PROG (PK)	D. No. Users	16.
3	15	18	6	56	1.86	14	15	2	30		

II. BASE PERIOD DATA

17.	18.	19. Condemnations A. Base	B. Depot O/H	C. Total	20. Depot Repaired	21.
-	-	—	—	-	-	—

III. RATES AND PERCENTAGES

NIS NRD

22. Cond % A. Base	B. Depot	23. % A. Base	B. Depot	24. Demand Rates A. Total OIM	B. OIM Depot	C. Base Rep	25. W/O %	26. W/O Base	27. A. ENG O/H	B. PDM	C.
0	.80	.50	.50	.4570	.2290	.2280	.10	.220			0

28. %	A. ENG O/H	B. PDM	C.	29.	30. A.	B.	C.	D. On Order	E. In Process	F. Total
(1) Repl					—	—	—	—	—	—
(2) W/O			0							

IV. OUT/OPERATING REQUIREMENT

NIM

Program Segment	A. Program	B. Rate	C. Requirement	D. $ Value
31. Update (REPLEN)				
32. OPERATING (REPLEN) PROC CYCLE/SL (INITIAL)	3 x 15 = 45	.0230	1.0	
33. Lead Time	18 x 15 = 270	.0230	6.2	
34. Depot Repair Cycle	1.86 x 15 = 27.9	.2290	6.4	
35. DEPOT SAFETY LEVEL (REPLEN)				
36. Base Repair Cycle	.20 x 30 = 6	.2280	1.4	
37. Base O&ST	.47 x 30 = 14.1	.2290	3.3	
38. Base Safety Level (REPLEN)				
39. Base Stock Level			4.7	

V. REPAIR REQUIREMENT – ENG OVHL MRS PDM

Program Segment		A. Program	B. Rate	C. Requirement	D. $ Value
40. Update (REPLEN)	JR				
	NJR	PDM Prog 3 month			
41. PROC CYCLE/SL (INITIAL) OPERATING (REPLEN)	JR	2 x 3 = 6	.20	1.2	
	NJR	proc months			
42. Lead Time	JR	2 x 18 = 36	.20	7.2	
	NJR				
43. Depot Repair Cycle	NJR	(12 days stock)			
44. Stock Level	JR	2 x 12 ÷ 30 = .8	.20	.2	
	NJR				
45. Floating Stock					

VI. ADDITIVES

46. WSM				
47. Other				

VII. REQUIREMENTS SUMMARY

48. Total Requirements	26.9	
49. Total Assets	0	
50. Net Procurement Requirement	27	$12150.00

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Figure 3-1.

Figure II-2. A Sample AFLCR 57-27 Worksheet

assessed for depot backorders. Depot backorders are considered only insofar as they influence base backorders.

Many data elements are required as input parameters to the METRIC model. These include the average base and depot repair times for each item, unit cost, Not-Reparable-This-Station (NRTS) rates, and average order and ship times. Minimum and maximum stock levels can also be specified, but are typically not used in applications of the model. In addition, the following assumptions are made:

1. A stationary compound Poisson probability distribution describes the demand process for each item.

2. There is no lateral resupply between bases.

3. There are no condemnations (all failed parts are repaired), nor are there any other gains or losses of assets to the system.

4. A failure of one type of item is statistically independent of those that occur for any other type of item.

5. Repair times are statistically independent.

6. There is no batching of items or other scheduling delays before repair is started on an item.

7. The level at which repair is performed depends only on the complexity of the repair.

8. All demand rates, NRTS rates, and other parameters required by the model are assumed known with certainty.

9. Items may have different essentialities; however, all items at a given base are considered to be equally essential.

The METRIC model computes a set of base stock levels and depot stock levels which are consistent with a given investment constraint. When used in this form,

the model can be used to determine the number of assets that should be procured to operate the system to support a given flying program. However, METRIC can also be used to resolve distribution problems. That is, the METRIC model can also be used to determine how to distribute a given number of assets across the depot and the bases so as to achieve the minimum expected backorder rate for this system.

<u>MOD-METRIC Model</u>

In METRIC a backorder of one item is assumed to be equally undesirable with a backorder with any other item. As noted above, however, many of the today's weapon systems have modular designs. In this case, the assumption that all backorders are equally undesirable is not necessarily a good approximation to the actual situation.

At best, a backorder for an LRU results in an aircraft that is not fully equipped to perform its assigned missions, while the worst situation corresponds to a grounded aircraft. On the other hand, backorders for SRUs result in delays in repairing the associated LRU. If these SRU backorders persist long enough, LRU backorders and inoperable aircraft will eventually result; however, this effect is usually not immediate. Clearly, aircraft availability is more immediately affected by LRU backorders than by SRU backorders.

In MOD-METRIC, it is assumed that the average base repair time B for a specific LRU is given by:

$$B = R + D$$

where:

R = Average repair time for the LRU assuming that all required SRUs are available, and

D = The average delay in the repair of the LRU due to the unavailability of needed SRUs.

The average LRU delay D may then be related to the stockage policies for the individual SRUs which are components of the LRU. For details of this calculation, see reference 1.

Recall that in METRIC, the objective is to minimize expected base backorders summed over all items (including both LRUs and SRUs) subject to an investment constraint; in MOD-METRIC, the objective is to minimize the expected base backorders of LRUs subject to an investment constraint on the total dollars allocated to both the LRU and its components. In MOD-METRIC, assumptions 2 through 8 of the METRIC model are assumed to hold. However, the METRIC assumption of the stationary compound Poisson probability distribution of demand (Assumption 1) is replaced by the assumption that demand obeys a simple Poisson process whose mean, M, is an unknown random variable. The prior probability distribution of this mean M is assumed to be gamma distributed. These MOD-METRIC assumptions for the demand process imply that the number of assets in the repair/resupply pipeline obey a negative -binomial distribution. This is the same probability distribution for the repair/resupply pipeline that is implied by the METRIC assumptions. Thus, the state probability calculations for both models are identical; however, they each rest on a different philosophical foundation, and may involve different input parameters. A second major difference between the METRIC and MOD-METRIC models concerns the assumed relationship among LRU and SRU components. The METRIC model ignores any relationships among items.

In contrast, MOD-METRIC explicitly considers LRU/SRU relationships. Specifically, in MOD-METRIC it is assumed that no more than one SRU failure causes the failure of the LRU. Of course, in real-world situations, there may be more than one faulty SRU in a failed Line Replaceable Unit. However, the MOD-METRIC assumption is a much closer approximation to the real world than the METRIC assumption of no LRU/SRU interactions.

Thus, MOD-METRIC provides a more detailed description of Air Force recoverable item part relationships than is provided by the METRIC model. However, the price for this increased detail in terms in data processing resources is a heavy one. The MOD-METRIC model requires information concerning the parts hierarchy of an aircraft--information that is not available in today's data systems. In addition, the MOD-METRIC optimization requires substantially more computer time than is required by the METRIC model.

VSL Variable Safety Level Computation

For follow-on buys of recoverable item spares, the Air Force uses a modification of Sherbrooke's METRIC model to determine world-wide requirements. This computation is known as the Variable Safety Level Computation (VSL).

In VSL, several techniques are used to reduce the computation effort required to determine requirements. First, VSL assumes that all bases are identical, each with the same demand rate, repair times, and base repair fractions. In this case, the optimum stock level for one base will be the optimum stock level for every base. This means that the set of optimum depot and base stock levels may be determined with the same amount of computational effort as that required to determine optimum levels in a two-base system, a substantial reduction in computation time over the original METRIC method. A second major change in

optimization techniques is the use of Lagrangian methods to obtain solutions, as opposed to the complete search method utilized in the original METRIC algorithm. A third important difference from the original METRIC model is the use of upper and lower limits to computed stock levels in the VSL computation. In VSL, a lower bound on the base stock level is set equal to the expected number of demands during an average base resupply time, while the lower limit for depot spares is set equal to the expected number of assets that are either in transit to the depot or in depot repair. Upper limits on both base and depot stocks are set so that no additional assets are allocated after system base backorders are reduced below a given threshold value. These upper and lower bounds restrict the number of asset positions which must be evaluated during the optimization process, and consequently reduce the amount of computational effort required to determine requirements.

The upper bounds used in VSL were adopted primarily to improve the computational performance of the algorithm. However, the lower limits represent a significant philosophical difference between the METRIC and VSL models. In METRIC, zero is the lower bound on base and depot stocks. In VSL, however, the lower limit is set so that every item will have enough stock at both the base and depot to take care of the expected demands during the resupply time. Thus, while METRIC uses marginal analysis to decide whether or not to stock each unit of an item, VSL first sets an item's stock level equal to the expected amount in the "pipeline." Marginal analysis is then used to determine how much additional stock will be allocated to each item. This constraint was insisted on by management because of METRIC's built-in basis against stocking high cost items, and because of a general feeling among Air Force managers that the resulting levels understated the base-level requirements for these items.

Another important difference between VSL and METRIC is in the modification of the unit price. In VSL, a modified unit price C' is obtained by multiplying the original price C by a discount factor. This discount is given by:

$$\text{Discount Factor} = 1 - \begin{matrix}\text{Fraction}\\ \text{of}\\ \text{Demands}\\ \text{Resupplied}\\ \text{from the depot}\end{matrix}$$

In no case, however, is this factor allowed to be less than .10. The modified price then replaces C in the optimization calculations. Thus, for an item that has a high percent of failures sent back to the depot for processing, the modified unit price will be only a small fraction of the actual unit price. On the other hand, for items with low levels of depot repair, the modified unit price will be close the actual unit price. In the VSL computation, this price modification tends to produce higher base stock levels for items with a small base processing rate. This modification was adopted because it was felt that high cost recoverable SRUs were not being stocked at the bases in sufficient quantities, and that high cost items also tended to have a small base processing rate. Consequently, the technique described above was used to "reduce" the cost of these items so that the algorithm stocks more of these items at base level. It was hoped that this approach would enable the VSL algorithm to retain the relative simplicity of the original METRIC algorithm, while obtaining results similar to those obtained from the MOD- METRIC algorithm which considers LRU/SRU relationships.

Section III

Data Used in this Study

In our study, we wished to reproduce as closely as possible the actual pattern of demands for recoverable items associated with F-15 and F-111 aircraft. To do this, several categories of historical data were sought. The categories include:

1. Repair times, unit cost data, and other identification data for each LRU and SRU peculiar to the F-15 and F-111.
2. Historical demand and reparable generation records for each of these LRUs and SRUs.
3. Flying programs for each of these aircraft, by base.
4. Base order and ship times.

In the following paragraphs, we discuss how this information was acquired.

Development of the Demand History Data Base.

To employ MOD-METRIC, it is necessary to identify all LRUs and their associated SRUs associated with a given aircraft. Unfortunately, such parts heirarchy information is not currently part of standard Air Force data systems. To obtain the required information, the Inventory Analysis Branch (AFLC/LORRA) first obtained from the Depot Data Bank a list of all XD3 items coded as peculiar to the F-15 or F-111 aircraft. LORRA then requested the item manager for each LRU to identify all SRU components of the LRU, and to delete from consideration all LRUs which contained common SRU components. LORRA then combined these lists, deleting all LRU/SRU families that had SRUs in common that where over looked in the item manager reviews. For example, if the same SRU was a

component of both LRU #1 and LRU #2, both of these LRUs and all related SRUs were deleted from the list. This process resulted in a list of LRUs with unique SRU components; that is, none of the SRUs were used in any other LRU. A summary of the item counts obtained from this effort is as follows:

	F-15	F-111	TOTAL
Original Number of LRUs	41	83	224
Remaining LRUs	15	7	22
Remaining SRUs	113	82	195

Mr. Don Skinn/ACZ-2 then developed computer programs to select unit cost, repair times, and other item identification data for each LRU and SRU from the D041 type "01" record contained in the Depot Data Bank (as of Cycle 79-3). Next, demand history information for each LRU and SRU on the list was accumulated. D041 Data Bank tapes for cycles 79-3 and 77-3 were used in the construction of this history. The result of this effort was a data file containing item identification and reparable generation data for all of these items covering the period July 1974 through June 1978. These demand histories were then printed and closely reviewed. During the review process, we sought to identify items which had missing or obviously erroneous information, or items in which the LRU and SRU data records were inconsistent. Of the 22 LRU groups in our final history tape, five contained serious deficiencies and were dropped from further analysis. The remaining 17 LRU/SRU groups were used for the remainder of our study. Table III-1 summarizes some of the major features of these 17 groups.

TABLE III-1.

TOTAL ACTIVITY FOR FY74-FY78 FOR LINE REPLACEABLE UNITS IN THE RIME DATA SET

Group No.	FSN	NOUN	Unit Price	BRGN	Base RTS	BCON	NRTS	Overhaul Facility DBGN	Overhaul Facility DCND	Depot Level Maintenance DREP	Depot Level Maintenance OVCN	Total Program PROG	No of SRUs	Total SRU BRGN
F-111 LRUs														
1	5841-00-2975357	SYNCHRO134	6,150	1980	1945	0	35	0	0	50	0	4248	1	124
2	5841-00-2475361	AMPL PS	5,798	1544	1520	0	24	1	0	46	0	4248	3	287
3	5841-00-4335541	ELECT UNIT	31,654	1510	1413	0	97	0	0	75	0	688	19	736
4	1270-00-1114649	AMPLIFIER	7,453	148	140	0	8	0	0	27	0	1409	4	29
5	1270-00-8694784	AMPL LD LN	7,725	77	69	0	8	0	0	15	0	1514	3	2
6	6605-00-2135882	BJBALL COMP	71,574	102	99	0	3	0	0	6	0	287	8	182
7	6605-00-2139886	BJBALL COMP	71,574	615	586	0	29	0	1	21	0	1120	7	706
8	5841-00-4163542	RTM 144	103,536	967	928	0	39	0	0	40	0	826	22	1,832
9	5841-00-4218433	SYNCHRO144	82,400	608	595	0	13	0	0	19	0	826	33	3,512
10	5841-00-3337343	MONITOR	6,887	497	456	0	41	0	0	22	0	3281	2	227
11	6605-00-2083423	BJCOMPUTER	262,182	2858	2757	0	101	8	0	103	0	1266	19	7,192
12	6606-00-2418979	BJBALL COMP	80,210	17	16	0	1	0	0	0	0	52	1	2
13	5841-00-1255144	CONTROL-BAD	4,674	74	65	0	9	0	0	6	0	883	1	162
F-15 LRUs														
14	5841-00-3939349	ANTENNABAD	177,192	876	763	0	113	0	0	1	0	883	5	395
15	5841-01-0032850	OSCILLATOR	48,800	449	320	0	129	0	0	23	0	883	2	51
18	5895-00-3278781	CONTROLPAN	2,814	147	90	0	57	1	0	39	0	974	1	31
19	5895-00-3409619	CONTROLPAN	2,957	59	54	0	5	0	0	3	0	1035	3	23

NOTE: BRGN = LRU Base Reparable Generations
RTS = LRUs repaired at base
BCON = LRU Base Condemnations
NRTS = LRUs Not Reparable This Station
DBGN = LRU Depot Reparable Generations
DCND = LRU Depot Condemnations
DREP = LRUs repaired at the depot
OVCN = LRU overhall condemnations
PROG = total installed program (in 100's of hours)

Flying Program Data

To determine flying hour programs for the F111 and F15 aircraft, Ms. Carol Hawks/LORRA first collected historical program data from G033 reports for the period July 1974 through July 1979. These reports display total flying hour programs by MDS, but provide no information on the distribution of these flying hours across bases. To determine the allocation of flying hours by base, Ms. Hawks studied the patterns of flying hours for each MDS for these aircraft, as well as other historical program data by Command. She then allocated the total flying hour programs by quarter to individual bases. Consequently, total flying hours used in our study exactly equal the total flying hours recorded for each of these aircraft. However, the individual flying programs by base do not necessarily represent the exact flying programs which were utilized in this period. However, the individual programs by base simulate the kinds of patterns which could be expected in Air Force operating enviornments, and provide a reasonable scenario for our study. Figures III-1 and III-2 present the flying hour programs by base for the F15 and F111 aircraft, respectively, obtained from this effort. As shown in Figure III-1, the F15 experienced a growing flying program during the 1974 through 1980 period. In July 1974, only one base of F15 aircraft was in operation. However, by July 1980, a total of eight bases were in operation, and the total flying hour program for the F15 had grown significantly. As may be seen in Figure III-1, the simulated flying program by base assumes that three pairs of bases have identical flying patterns; these are the base pairs 3 and 4, 5 and 6, and 7 and 8,

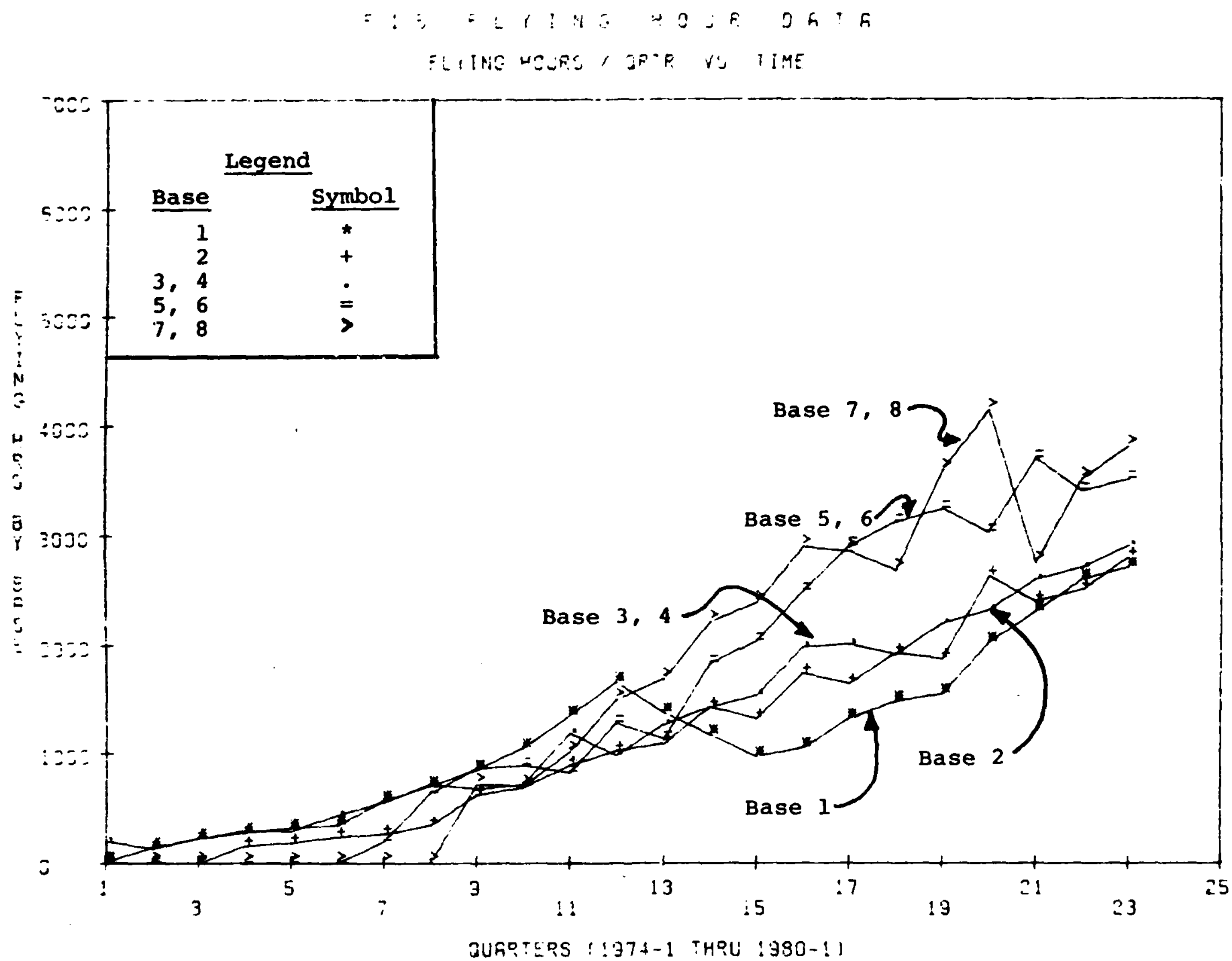

Figure III-1, Simulated F15 Flying Hour Programs by Base

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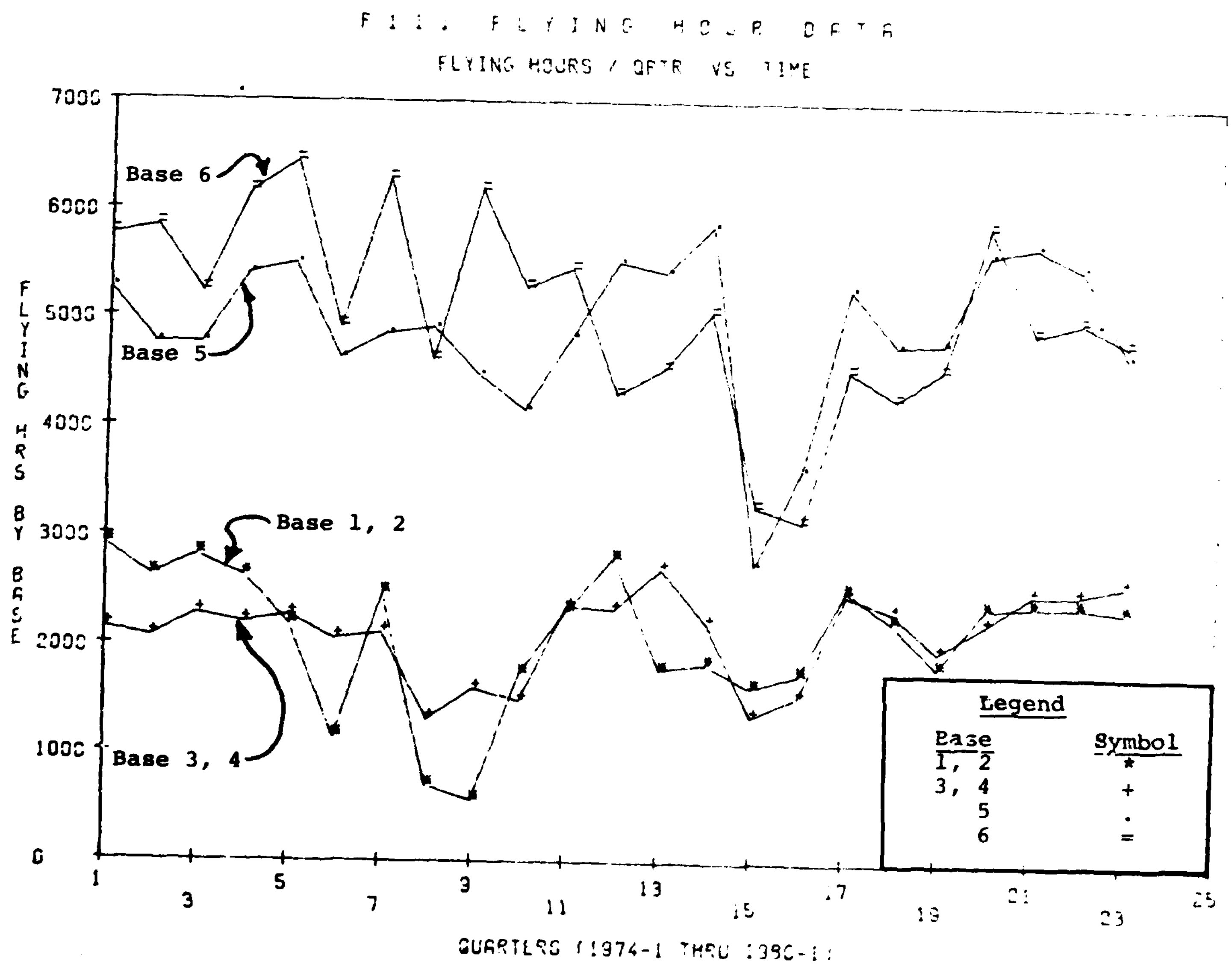

Figure III-2, Simulated F111 Flying Hour Programs by Base

respectively. Although it is doubtful that any two bases ever have exactly the same flying programs in real world systems, the programs used appear to be reasonable approximations.

Figure III-2 presents the simulated flying hour program by base for F111 aircraft for the period July 1974 through July 1980. As may be seen from the figure, the F111 aircraft was already a mature member of the Air Force fleet in July 1974. During the 1974 through 1980 period, the flying program for this aircraft remained fairly stable. As may be seen from the figure, our simulation scenario assumes that there are six F111 operating bases, and that the base pairs 1 and 2, and 3 and 4, each have identical flying programs.

Order and Ship Times

An important input to both the MOD-METRIC and METRIC models is the average Order and Ship time for each stocking location of a given LRU or SRU. Unfortunately, we were unable to find any historical data describing actual Order and Ship times by base. Consequently, a simulation procedure was used to construct representative values for order and ship times.

To do this, Ms. Hawks obtained samples of Order and Ship times (O&ST) from the D143 data system. This system presents average O&ST by base. After a study of this data and following several discussions with distribution specialists, the data presented in Table III-2 was developed. This information contains deviations in days of the average Order and Ship Times for specific bases from the worldwide average Order and Ship times for specific items. This deviation data is used to construct O&ST values by base using the average LRU O&ST as a starting point. To see how this data is used, suppose that a specific LRU has an average Order and

Ship time of 10 days. Further, suppose this LRU is a component of the F111 aircraft. In simulating this LRU, we would assume that the Order and Ship time for base 1 was equal to (10 - 6) = 4 days, while the Order and Ship time for base 3 would be set to (10 + 9) = 19 days. Using similar calculations, we would obtain the set of Order and Ship times shown in Table III-3. These values would then be used in the simulation of this specific LRU.

TABLE III-3

CALCULATED ORDER AND SHIP TIMES (OST)
FOR AN F-111 LRU WHOSE AVERAGE OST IS 10 DAYS

Base Number	Order and Ship Time (Days)
1	4
2	4
3	19
4	19
5	8
6	6
Average	10

Section IV.

An Overview of

The Recoverable Item Management Evaluation System

As noted earlier, the object of this study is to evaluate the relative performance of METRIC, MOD-METRIC, VSL and variants of these methods in a real-world context. To do this, we constructed a detailed simulation model of Air Force recoverable item flows. This model is called the Recoverable Item Management Evaluator (RIME). A detailed description of RIME is presented in Reference 2. In this section, we outline the major features of this model. Areas to be discussed in this section include:

1. Logistics flows modeled in RIME.
2. Major Components of RIME.
3. Event Generation.
4. Stock Level Computations.
5. The Simulation Scenario.

Logistics Flows

The Recoverable Item Management Evaluator simulates the flows of a Line Replaceable Unit (LRU) and its associated Shop Replaceable Unit (SRU) components in a multi-location logistics system such as that illustrated in Figure IV-1. As shown in the figure, any particular LRU or SRU may be stocked at any one of several possible locations. Three major categories of inventory stocking locations are modeled in RIME. These are:

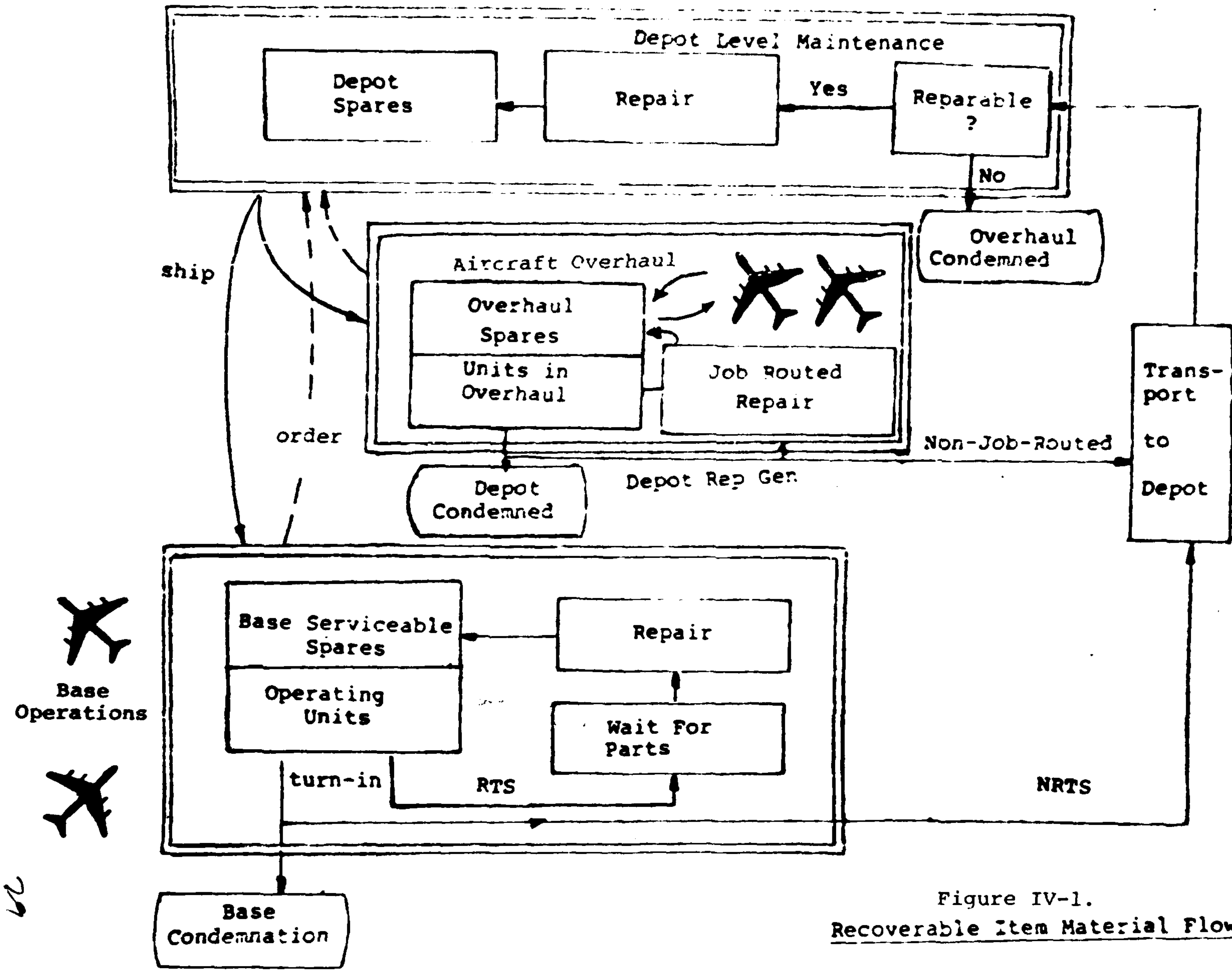

Figure IV-1.
Recoverable Item Material Flows

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1. Operating Bases.
2. Depot Level Maintenance Facilities.
3. Aircraft Overhaul Facilities.

Let us now consider each of these categories in more detail.

Operating Bases represent locations from which major Air Force units such as aircraft wings or squadrons are operated. These operations generate failed LRU and SRU components, as well as demands for serviceable replacements for the failed units. As shown in the figure, some of these assets may be repaired at base level while other assets are Not Repairable at This Station (NRTS) and are thus returned to the depot for repair. Those assets which can be returned to a serviceable condition by the base repair shops are said to be "Repairable at this Station", or RTS assets. Still other assets that fail at base level may be beyond repair. These assets are condemned, and requisitions for serviceable replacements are submitted to the depot supply organization.

The Depot Level Maintenance Facility performs two major tasks; these are: (a) the repair of failed LRUs and SRUs which have been returned to the depot, and (b) maintenance of the centralized source of supply which may be used to replenish operating bases. As shown on the upper right hand side of Figure IV-1, not all assets which are returned to the depot are repairable. Some of them are beyond repair and are thus condemned at the depot. We say that such assets are "Overhaul Condemned," using the same terminology as that employed in the D041 system.

In RIME, the Overhaul Facility represents a repair organization which generates unserviceable LRU and SRU components as a result of the overhaul of major end items. In our case, the major end items are F-15 and F-111 aircraft. Unserviceable components that generate at the Overhaul Facility may be classed

into one of two different categories. These are: (a) Job-Routed components -- components which are repaired at the maintenance shops of the Overhaul Facility itself, and (b) Non-Job Routed components -- components that must be sent to the specialized Depot Level Maintenance Facility for repair. In current Air Force data systems, no historical records exist on the magnitude or timing of job-routed repairs. Consequently, job-routed recoverable item flows are not modeled in RIME. However, RIME does model asset flows associated with Non-Job-Routed components. As shown in the figure, we assume that all Non-Job-Routed components fall into one of two different categories: (a) if the component is beyond repair, it is condemned at the overhaul facility. In the D041 system, such assets are called "Depot Condemned" assets. (b) On the other hand Non-Job-Routed assets which are not condemned at the Overhaul Facility are returned to the Depot Level Maintenance facility for repair. In RIME, we assume that all Non-Job-Routed assets must be shipped to another location for such repair. That is, we assume that the Overhaul Facility and the Depot Level Maintenance facility are at physically-distinct geographic locations.

Major Components of RIME

Figure IV-2 illustrates the major components of the Recoverable Item Management Evaluator System. As shown in the figure, this system consists of four major components. The D041 Data Extraction System is used to obtain required D041 historical data elements from the D041 Data Bank, and to reformat this information into the specific record layout requirements of this study. The development of this system is described in Section III. The Exogeneous Event Generation System utilizes historical D041 demand for a given LRU/SRU family,

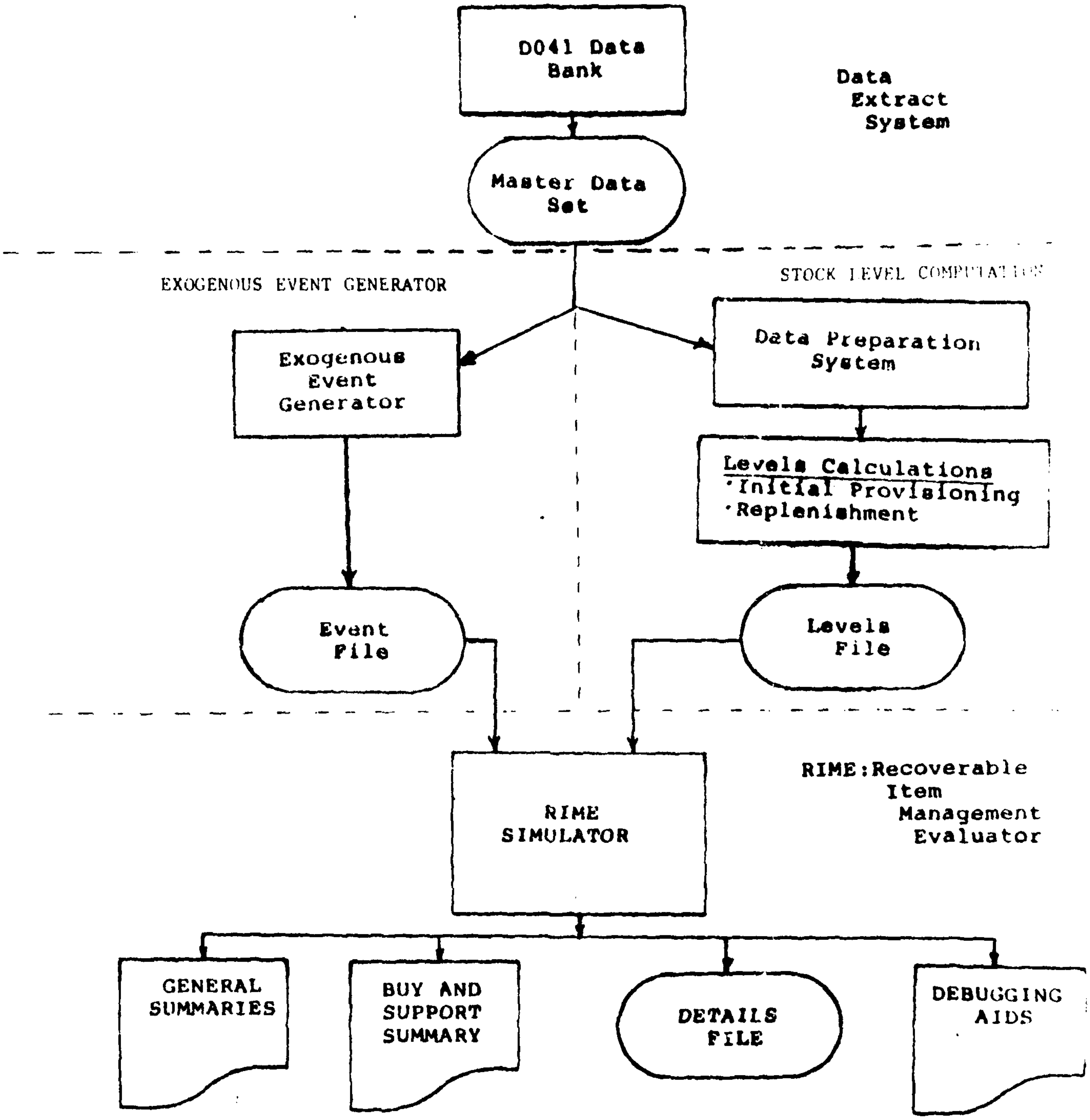

Figure IV-2.

Major Components in RIME System.

and uses a Monte Carlo process to convert the aggregate data into individual reparable generation events. The result of these computations is an Event File which identifies the precise timing and location of individual reparable generation events, and all associated failure and demand activities which may be derived immediately from the reparable generation event. Reference 2 contains a detailed description of the Exogenous Event Generation process.

In the Stock Levels Computation module of RIME, appropriate algorithms are utilized to estimate the Mean Time Between Demands (MTBD), NRTS rates, condemnation factors, and other parameters required by specific stock level computation routines. The computation system then utilizes specified optimization algorithms to compute stock levels for each period to be simulated within the RIME model. Finally, the RIME Simulator is used to estimate the buy-dollars and backorder and fill rates associated with the computed levels. Outputs from the Evaluator include totals of reparable generation, repair, procurement, backorder, and fill activity for each simulated quarter, aggregate summaries of buy-dollars and support statistics totaled across all simulation quarters, and detailed results by LRU/SRU group. The extent of output products produced by the Evaluator is determined by parameters specified as inputs to the Evaluator routine.

In the next section, we discuss the Event Generation Process, while the Stock Levels Computation module is discussed in the subsequent section.

The Event Generation Process

A major design feature of the RIME evaluation model is that all recoverable item flows are driven by actual Air Force histories of recoverable item activity. For example, Table IV-1 presents historical data from the D041 Depot Data Bank for Federal Stock Number 5841-00-2475357 This FSN is a Line Replaceable Unit

Table IV-1
D041 Reparable Generation Data
For FSN 5841-00-2475357
An F-111 LRU

Noun: SYNCHRO134
Price: $6,150

Data Element	Description	Code	Quarter FY74-1 LRU	Quarter FY74-1 SRU	Totals for FY74-1 thru FY78-4 LRU	Totals for FY74-1 thru FY78-4 SRU
1.	Reparable Generations	BRGN	115	10	1980	124
2.	Assets Repaired at This Station	RTS	110	2	1945	10
3.	Base Condemnations	CON	0	0	0	1
4.	Assets Not Reparable at This Station	NRTS	5	8	35	113
5.	Depot Reparable Generations	DBGN	0	0	0	2
6.	Depot Condemned	DCND	0	0	0	0
7.	Depot Repaired*	DREP*	5*	10*	50*	103*
8.	Depot Overhaul Condemned	OVCN	0	0	0	0
9.	Installed Program (*100's hours*)	PROG	300	300	4248	4248

* The total number of assets which completed repair in a given quarter is available from the D041 Depot Data Bank. However, this information is not used in RIME, since these numbers reflect the performance of past inventory management policies, and that are not necessarily representative of the inventory management rules to be evaluated.

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for the F-111 aircraft with a price of $6,150 per unit. This LRU has a single SRU component; the SRU is FSN 5841 00-4899855, a SYNC ASSY with a unit price of $452.20. Table IV-1 presents the repairable item generation data for these two stock numbers for the first quarter of FY74, as well as the total repairable generations in each category shown for the four year period from FY74-1 through FY78-4.

As shown in the table, this LRU had 115 repairable generations during the first quarter of FY74. Of this total, 110 were repaired at base level, while 5 were NRTS assets. That is, five assets were returned to the depot for repair. None of the total of 115 assets were condemned at the base level, and there were no depot repairable generations of this LRU during FY74-1 (i.e., there were no generations from the Overhaul Facility). During this quarter, the LRU had a total installed program of 30,000 hours. Similarly, the SRU had 10 repairable generations during this quarter. Two of these were repaired at base level, while 8 were returned to the depot.

In simulating this LRU/SRU family for the quarter FY74-1, exactly 115 repairable generations of the LRU are created in the RIME model, with exactly 110 of these to be repaired at base level. Similarly, exactly 10 SRU repairable generations are created in the simulation of this quarter, with 2 repaired at base level and 8 returned to the depot. In a simulation of the entire FY74-1 through FY78-4 interval, exactly 1980 LRU generations would be created, and exactly 124 SRU generations. Similarly, all of the other historical data displayed in Table IV-1 would be exactly reproduced by the simulation model.

One problem in simulating detailed repairable item flows from Air Force historical data is that the historical data is maintained in an aggregated form.

That is, the historical records only tell us the total number of repairable generations that occurred at all base locations during a given interval, and provides no information in terms of which specific bases generated these failures. Similarly, the historical records provide no data which allow us to link up specific SRU repairable generations with associated LRU failures. Consequently, it was necessary to devise probability models to interrelate LRU and SRU reparable generations. Table IV-2 presents the assumptions utilized in our demand generation process. Basically, the rules presented in this table are based on a relatively small number of fundamental assumptions. These are (a) Air Force D041 recoverable item flow histories are to be reproduced as closely as possible in the simulation process, (b) the probability that a specific SRU failure in a given quarter is related to a given LRU repairable generation is assumed proportional to the total number of SRU units that are contained in the assemblies of the failed LRUs. For example, for the LRU/SRU pair presented in Table IV-1, there are two units of the SRU contained in each LRU; that is, the Quantity Per Application (QPA) for the SRU is two. Consequently, for the 110 LRUs that were repaired at base level during FY74-1, there were 2 X 110 = 220 SRUs contained in the 110 LRU repairable generations. Further, since there were exactly 10 repairable generations for the SRU during this period, we assume that the probability that any specific SRU component was faulty is 10/220.

In analyzing Air Force historical records, we were unable to relate condemnation actions recorded in one period to specific repairable generation actions recorded in other periods. Consequently, in simulating both depot condemned and depot overhaul condemned actions, we use a probability model which guarantees that the total number of condemnations over the four year simulation period

Table IV-2

Basic Assumptions of RIME Reparable Generation Probability Model

I. Base Reparable Generations

1. The probability that a specific LRU reparable generation occurs at a given location is proportional to the flying activity at that location relative to the total flying activity at all locations in the specific quarter under consideration. Further, it is assumed that a uniform distribution describes the probability that a given LRU rep gen occurs at any specific instance within the quarter under consideration. This is equivalent to assuming that LRU reparable generations follow a simple Poisson process within the specific quarter of interest. However, the exact number of LRU reparable generations within a given quarter exactly equals the historical values recorded in D041.

2. The probability that a given SRU rep gen (RTS, NRTS, or condemnation) is related to a given LRU rep gen is equal to the ratio of the total SRU rep gens in a given quarter to the total number of SRUs installed in LRUs that fail during that quarter. We refer to this as the Exposure Probability model. Once an SRU rep gen is related to a specific LRU rep gen, the clock times for related SRU events are determined by adding appropriate time delays to the LRU failure time.

3. If recorded D041 LRU rep gens exceed recorded D041 SRU rep gens, it is assumed that some LRUs were repaired without requiring replacement SRUs. Calibration and adjustment actions and job-routed repairs are examples of this situation.

4. If recorded D041 SRU rep gens exceed the total SRUs installed in failing LRUs, we assume the excess units are "independent SRU demands"; that is, demands that are independent of an associated LRU turn-in to base supply. This situation will occur if an LRU is repaired at the flight line, rather that in the base maintenance shops.

5. If an LRU is condemned, all SRUs in the condemned LRU that are not reparable or condemned are treated as serviceable returns to the supply system.

II. Depot Reparable Generations

1. LRU depot delays are simulated using the same assumptions employed in the METRIC and MOD-METRIC models; namely, LRU depot delays are treated as independent random variables, independent of SRU stock status at the depot. Hence, although the LRU repair time may include an allowance for parts delays, these delays are not explicitly simulated.

2. Since all LRU depot delays are treated as independent random variables, all SRU depot reparable generations are also treated as "independent"; that is, these generations are not related to any of the LRU generations.

Table IV-2 (Cont'd)

3. It is assumed that the specific time that a given LRU or SRU depot reparable generation occurs is uniformly distributed over the specific quarter under consideration. This is equivalent to assuming that both LRU and SRU depot rep gens obey simple Poisson processes.

III. Forecasting Assumptions

1. All values for Mean Time Between Demands (MTBD), NRTS rates, and condemnation rates are based upon eight-quarter moving averages of past reparable generation activity. However, at least four quarters of data are always used for these estimates. Hence, to estimate these values at the beginning of FY74-1 we use the D041 data for quarters FY74-1 through FY74-4, since no data prior to FY74-1 is available. To estimate rates to be used in simulating FY77-1, however, we use the D041 data for the eight quarters between FY75-1 and FY76-4. This interval represents the most recent eight-quarters of historical data that would be available at the start of FY77-1.

2. For operating bases, forecasts for future rep gens are based upon historical failure rates and the actual D041 program activity for the future period. Specific LRU installed programs by base are determined by allocating the total LRU program in proportion to the aircraft base programs shown in Figures III-1 and III-2, as appropriate. For forecasts of Aircraft Overhaul requirements, it is assumed that the expected depot rep gen rate may be forecast perfectly over a one year time horizon; however, it is further assumed that errors occur in forecasting the precise time within the year that these depot rep gens occur.

3. All depot reparable generations are assumed to originate from a single aircraft overhaul facility. Stock levels for this facility are computed to provide a 14-day supply.

exactly equals the number of condemnations recorded in Air Force repairable generation histories. However, we do not attempt to reproduce the specific quarter-by-quarter condemnation quantities which are recorded in the D041 Depot Data Bank.

Stock Level Computations

The management of recoverable item inventories involves providing answers to three basic questions. These are:

1. When will recoverable spares be needed?
2. How much is needed?
3. Where should the spares be located?

The first two questions are Procurement issues, for they determine how much stock is needed to support a given system, and when this stock should be acquired and brought into the Air Force supply system. The third question, on the other hand, is a Distribution issue. The answer to this question determines at which locations the currently available stock should be positioned.

Two distinct phases may be identified during the life cycle of a given item. These are the Initial Provisioning Phase and the Replenishment Phase. The Initial Provisioning Phase determines the number of assets which will be acquired during the initial buy of an asset, while the Replenishment Phase determines the number of additional assets which are required to compensate for (a) condemnations resulting from operations, (b) unexpectedly high failure rates, or (c) increased levels of program activity. Different computational methods may be used in each of these phases to determine recoverable item spares requirements.

TABLE IV-3

CODES EMPLOYED TO SIMULATE
ALTERNATE INVENTORY MANAGEMENT METHODS

COMP CODE	COMPUTATIONAL METHOD	MOD-METRIC COMPUTER PROGRAM
1	METRIC	MOD-METRIC/ONEIND
2	MOD-METRIC	MOD-METRIC/TWOIND
3	VSL	MOD-METRIC/ONEIND, with all bases assumed equal, and with upper and lower bounds
4	AFLCR 57-27	R57-27, a modification of a CREATE Time Sharing program written by Mr. T. Mitchell, AFALD/XRS.

IMETH = Initial Provisioning Computation Code
KMETH = Replenishment Computation Code

of MOD-METRIC computer programs provided no way of computing requirements using logic specified in AFLCR 57-27. However, Mr. Terry Mitchell of AFALD/XRS previously implemented a CREATE Time Sharing Program to accomplished this. We converted Mr. Mitchell's program to a subroutine to provide an AFLCR 57-27 computation capability in our Stock Levels Computation system.

To automate the levels computation process, it was convenient to assign codes to identify each of the basic stock level computation methodologies. These codes are shown on the left-hand side of Table IV-3. As shown in the table, the code IMETH is used to identify the computational methodology used for Initial Provisioning Calculations, while the code KMETH is used to specify the computational method for replenishment computations. Thus, IMETH = 1 indicates that the ONEIND program is to be used in initial provisioning calculations in accordance with METRIC math model assumptions, while KMETH = 1 indicates the same calculation is to be performed during the replenishment phase. Similarly, IMETH = 2 indicates that the TWOIND program is to be used to represent MOD-METRIC calculation methods in the initial provisioning phrase, while KMETH = 2 indicates TWOIND is to be used for replenishment calculations.

The computation codes IMETH and KMETH specify the general computational method to be used for Initial Provisioning and Replenishment Calculations, repsectively. However, three other pairs of codes are also used in RIME to completely specify a stock level computation method. These additional codes are defined in Tables IV-4 and IV-5.

Table IV-4 defines two additional codes defining required manipulations of input data to the ONEIND and TWOIND programs. The codes IEQBAS and KEQBAS define whether or not base-to-base differences are to be recognized during stock

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TABLE IV-4

Levels Calculation Codes

NOTE: IMETH, IEQBAS, and ICOST apply to Initial Provisioning Calculations
KMETH, KEOQBAS, and KCOST apply to Replenishment Calculations

Fortran Variable	Description	Value	Effect	Calculation
IMETH, KMETH	Method Code	1	Use ONEIND Model for all items	Set IC1=IC2=1. (All items are treated as LRUs)
		2	Use TWOIND Model for all LRU/SRU groups	IC1=2 for LRU; IC1=3 for SRU. (LRU/SRU relationships are considered)
		3	Use ONEIND to determine qty, and EVALUATE to distribute assets	IC1=IC2= 1. (All items are treated as LRUs)
		4	Use AFLCR 57-27 logic and evaluate for all items	IC1=IC2 = 1 (All items are treated as LRUs)
IEQBAS, KEQBAS	Equal Bases Code	0	Treat Bases as read in	Base-to-base differences are recognized.
		1	Equal Base Assumption	Set output flying hours and order and ship times (FH(K) and OST(K)) equal to the average values for output
ICOST KCOST	Unit Cost Code	0	Unit Cost is Unchanged	Discount is not used.
		1	Set unit cost to (Unit Cost) (Discount)	Discount equals greater of .10 or (1.- NRTS fraction)

NOTE: IEQBAS and KEQBAS are used in program ONEIND only; no other program uses these variables.

TABLE IV-5
Stock Level Bounds Codes

Fortran Variable	Description	Value	Effect
IMINSK KMINSK	Bounds Code	0	No bounds are used.
		1	Set lower bound to expected number as assets in repair/resupply pipeline; set upper bound to BOMIN
BOMINI, BOMINK	Value of Upper Bound	.001	In ONEIND calculations, this variable specifies an upper bound on expected system backorders. Once system backorders are reduced to this value, no additional assets are allocated.
		.01	In TWOIND calculations, BSTOP is set to this value. BSTOP is the reduction in expected backorders per additional million dollars invested at which stock level allocations are stopped.

NOTE: IMINSK and BOMINI apply to Initial Provisioning Calculations
KMINSK and BOMINK apply to Replenishment Calculations

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levels computations. If the code equals 0, base-to-base differences are recognized. On the other hand, if the code equals 1 all bases are assumed to be equal. In the latter case, the stock level computations are performed by replacing input values for flying hour programs and order and ship times for each base by the respective average values for all bases combined. This latter data modification is required to represent the Equal Base Assumption employed in the VSL computation.

The codes ICOST and KCOST specify whether or not the cost discount computation utilized in VSL is to be employed. If this code equals zero, stock level computations are performed without any modification to the D041 unit cost. On the other hand, if the code equals 1, the D041 unit cost is multiplied by a discount factor which equals the greater of .10 or (1.-NRTS fraction). Code ICOST applies to initial provisioning predictions, while the code KCOST specifies the replenishment calculation method.

Table IV-5 specifies four variables used in establishing upper and lower bounds upon computed stock levels. The variables IMINSK and BOMINI are employed to specify bounds on initial provisioning calculations, while KMINSK and BOMINK specify values to be used in replenishment decisions. If the code IMINSK equals zero, no upper or lower bounds are used in the initial provisioning calculations. On the other hand, if the Bound code IMINSK is 1, all stock levels are computed with a lower bound equal to the expected number of assets in the repair/resupply pipeline, and an upper bound specified by Upper Bound Variable BOMINI. Specific numerical values for upper bounds used in this study and their interpretation are given in Table IV-5. The above discussion applies to the variable IMINSK and BOMINI used to bound initial provisioning calculations. However, similar comments apply to the use of the variables KMINSK and BOMINK used to bound replenishment stock levels.

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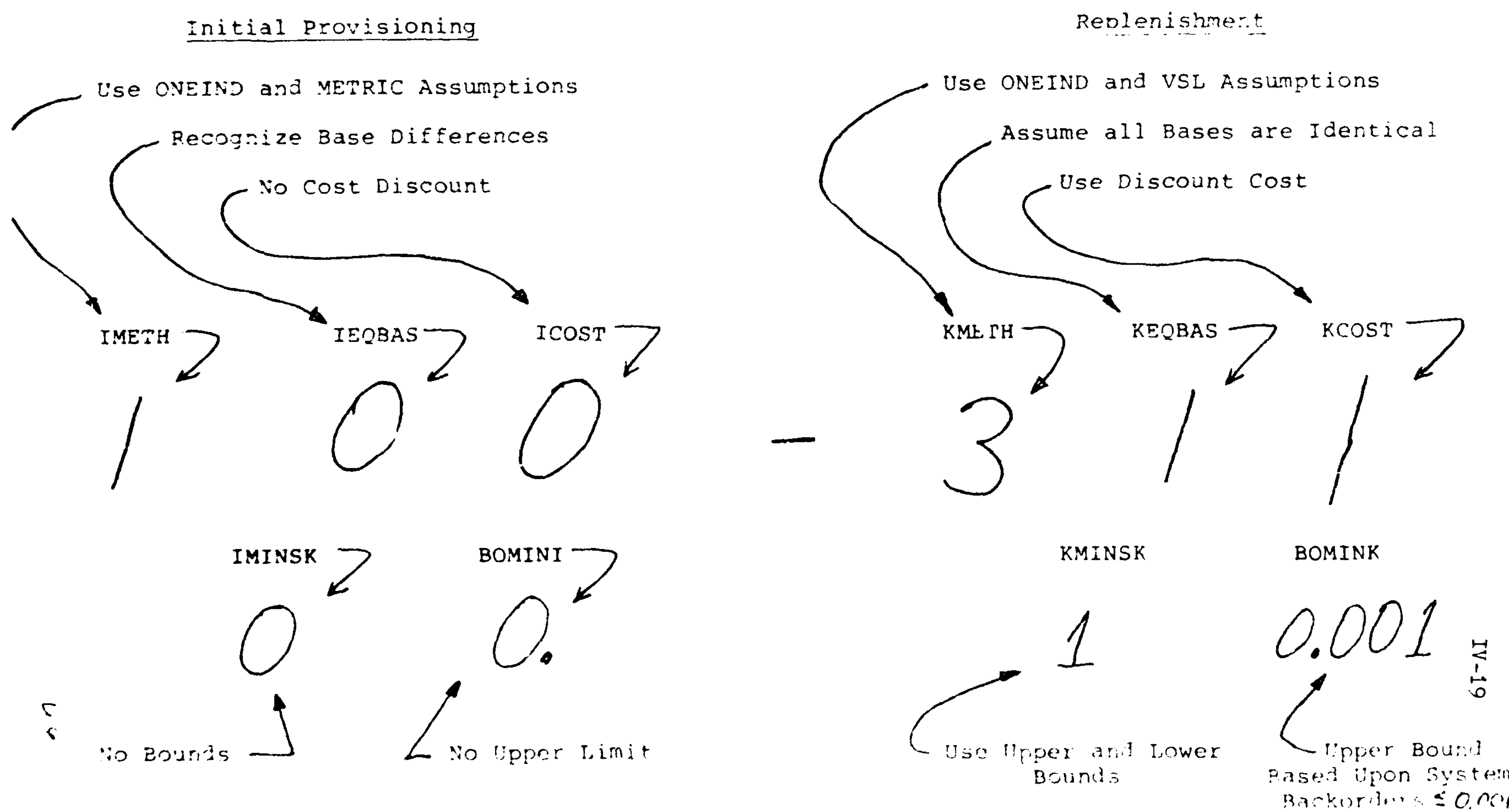
From the above discussion, ten numerical values are required to specify an inventory management policy for both initial provisioning and replenishment calculations. Five codes (IMETH, IEQBAS, ICOST, IMINSK, and BOMINI) are required to specify an inventory management policy for Initial Provisioning calculations, while five additional codes (KMETH, KEQBAS, KCOST, KMINSK, and BOMINK) are required to specify Replenishment calculations. For example, Figure IV-3 illustrates the inventory management code 100-311 0 0/1 0.001. As shown in the table, the first three digits (100) specify that the ONEIND program is to be used to represent the METRIC computation algorithm; base-to-base differences are to be recognized; and finally, no cost discount factors are to be employed. The first set of bounds (0 0) specify that no upper or lower limits are to be used in stock level computations for initial provisioning. On the other hand, the replenishment code 311 indicates that the ONEIND program is to be used with Variable Safety Level assumptions. Since KEQBAS equals 1, all base variables are to be set to the average base values in these calculations. Further, since KCOST equals 1, a discontinued unit cost is to be used. Finally, the set of bounds (1 0.001) indicate that both upper and lower limits are to be applied after the stock levels have been computed. The lower limit is to be the expected number of assets in the repair/resupply pipeline, while the upper bound on base stock levels is to be computed based upon minimum system backorders of 0.001.

The Simulation Scenario

In previous sections, we have discussed the data available for this study, general inventory computation methods, and coding schemes for identifying particular inventory calculation techniques. This section discusses the specific inventory policies selected for evaluation in this study, and the major assumptions used in the simulation scenario.

FIGURE IV-3

Illustration of a Complete Inventory Management Code



As discussed earlier, we wish to evaluate the relative cost effectiveness of several proposed methods for managing Air Force recoverable item inventories. Thirteen specific inventory management policies were selected for detailed evaluation. These policies are identified in Table IV-6. The three columns on the left-hand side of Table IV-6 indicate the policy number assigned to identify each policy and the codes used to specify the initial provisioning and replenishment calculations required by each policy. For example, policy number 3 has a Compute Code of 101-101, and a Bounds Code of 0 0/0 0. As discussed in the previous section, this code specifies the use of the program ONEIND for initial provisioning calculations and for replenishment calculations. Further, the bounds code indicates that no upper or lower bounds are to be used in limiting the stock levels computed by this routine. As shown on the right-hand side of the table, policy number 3 represents the use of Sherbrooke's original METRIC model, but using a discounted unit cost. The specific characteristics of each of the other policies shown in Table IV-6 may be determined using the code definitions presented in Tables IV-4 and IV-5.

To evaluate the relative cost effectiveness of these policies, we utilized the available D041 data histories to evaluate how well each one of these proposed methods would have performed had they been employed during the FY74 through FY78 period. The basic rules used in simulating this time interval are shown in Figure IV-4.

As shown in the figure, 16 quarters of history were available for this study. The oldest available data described reparable generations during the first quarter of FY74, while the most recent available data described reparable generations during the fourth quarter of FY78. In our simulation, we wished to simulate both

TABLE IV-6

POLICIES EVALUATED

POLICY NO.	COMPUTE CODE	BOUND CODE	INITIAL PROVISIONING PROGRAM	INITIAL PROVISIONING EQUAL BASES	INITIAL PROVISIONING COST DISCOUNT	INITIAL PROVISIONING BOUNDS	REPLENISHMENT PROGRAM	REPLENISHMENT EQUAL BASES	REPLENISHMENT COST DISCOUNT	REPLENISHMENT BOUNDS	DESCRIPTION
1	100-100	0 0/0 0	ONEIND	NO	NO	NO	ONEIND	NO	NO	NO	METRIC
2	310-310	0 0/0 0	ONEIND/ EVALUATE	YES	NO	NO	ONEIND/ EVALUATE	YES	NO	NO	METRIC WITH EQUAL BASES
3	101-101	0 0/0 0	ONEIND	NO	YES	NO	ONEIND	NO	YES	NO	METRIC WITH COST DISCOUNT
4	100-100	1.001/ 1.001	ONEIND	NO	NO	YES	ONEIND	NO	NO	YES	METRIC WITH BOUNDS
5	311-311	1.001/ 1.001	ONEIND/ EVALUATE	YES	YES	YES	ONEIND/ EVALUATE	YES	YES	YES	VSL
6	200-200	0 0/0 0	TWOIND	NO	NO	NO	TWOIND	NO	NO	NO	MOD-METRIC
7	200-200	1 .01/ 1 .01	TWOIND	NO	NO	YES	TWOIND	NO	NO	YES	MOD-METRIC WITH BOUNDS
8	400-311	0 0/ 1 .001	R57-27/ EVALUATE	N/A	N/A	N/A	ONEIND/ EVALUATE	YES	YES	YES	AFLCR 57-27 FOR INITIAL PROVISIONING. VSL FOR REPLENISHMENT. METRIC FOR DISTRIBUTION
9	200-311	0 0/ 1. 001	TWOIND	NO	NO	NO	ONEIND/ EVALUATE	YES	YES	YES	MOD-METRIC FOR INITIAL PROVISIONING. VSL FOR REPLENISHMENT BUYS. METRIC FOR DISTRIBUTION.
10	200-311	1 .01/ 1 .001	TWOIND	NO	NO	YES	ONEIND/ EVALUATE	YES	YES	YES	POLICY 9 WITH BOUNDS
11	400-100	0 0/ 1 .001	R57-27	N/A	N/A	N/A	ONEIND	NO	NO	YES	AFLCR 57-27 FOR INITIAL PROVISIOING. METRIC FOR DISTRIBUTION.
12	200-100	0 0/ 1 .001	TWOIND	NO	NO	NO	ONEIND	NO	NO	YES	MOD-METRIC FOR INITIAL PROVISION, METRIC FOR DISTRIBUTION
13	200-100	1 .01/ 1 .001	TWOIND	NO	NO	YES	ONEIND	NO	NO	YES	POLICY 12 WITH BOUNDS ON INITIAL PROVISIONING

INITIAL PROVISIONING PHASE

(a) Compute initial provisioning levels using actual data for quarters FY74-1 thru FY74-4.

(b) Assume all assets are serviceable and on-hand at individual stocking locations at time zero.

(c) Initial provisioning stock levels are used to manage inventories for the first six months of the simulation. After that, replenishment levels are used.

REPLENISHMENT PHASE

(a) Compute stock levels using up to 8-quarters of history to develop moving average forecasts for MTBD, NRTS rates, and condemnation rates.

(b) Forecast installed programs are set equal to the observed D041 installed program for the LRU. The total LRU installed program is assumed distributed by base in proportion to aircraft flying activity by base.

(c) If a base is below its authorized stock level, it submits requisition to the depot. Lateral redistribution of assets is not simulated, and requisitions are never cancelled.

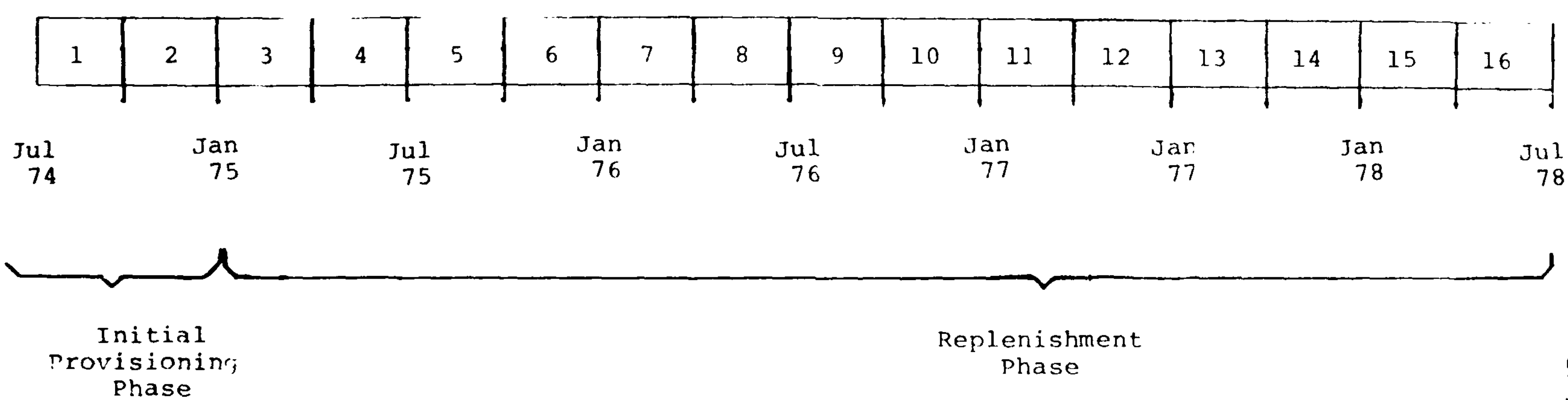


Figure IV-4

Major Assumptions in the Simulation Senario

initial provisioning and replenishment phases of an item's life cycle. To do this, the simulation model assumes that initial provisioning calculations were completed sometime prior to July 1974, and that all associated initial provisioning assets are serviceable and on hand at the individual stocking locations at the beginning of July 1974. Further, the initial provisioning stock levels are used to manage inventories for the first six months of the simulation. After that, stock levels are computed using the computational rules for the replenishment phase.

During the replenishment phase, stock levels are recomputed each six months. In performing a stock level computation, up to 8 quarters of history are used to develop moving average estimates for Mean Time Between Demands (MTBD), NRTS rates, and condemnation rates. Forecast of installed LRU and SRU programs are set equal to the observed D041 installed program for the LRU. This total installed program is assumed to be distributed by base in proportion to the aircraft flying activity by base. Plots of the flying activity for F-15 and F-111 aircraft are presented in Section III.

As described earlier, stock levels are computed as a preprocessing step to the RIME model, and read in as needed during a run of the Recoverable Item Management Evaluator. Following a stock level computation, the stocks available at each stocking location are compared to the authorized level. If a base is below its authorized level, it submits a requisition to the depot. If a base is over its authorized level, no action is taken. Hence, lateral redistribution of assets is not simulated in this model. Assets only leave a base as a result of NRTS actions. Consequently, if an item is in a overstocked position, it may be some time before the excess assets are returned to the depot. We refer to this method of distribution as the "trickle-back" policy.

Buy Support Objective (BSO)

The Buy Support Objective, X, serves a special role in the stock level computations for the METRIC, MOD-METRIC, and VSL computations. This factor represents a cut-off parameter used in stock level computations. If the expected reduction in system backorders per dollar invested is less than X, no additional stock is allocated. Hence, if the value of X is large, the optimum value of safety stocks will be small. Conversely, a small value of X will produce a high level of safety stock investment, and a relatively low level of expected base backorders. Thus, the parameter X is a "management control knob" that controls the relationship between stock levels and system backorders.

The parameter X directly controls the stock level for every inventory item. The smaller the value of X, the larger the computed stock level will be. But, the stock level also controls the amount of buy notices that will be triggered in a given time period. Hence, the Buy Support Objective X may be used to control the amount of money spent in a given fiscal period. Smaller values of X will lead to higher stock levels, and thus to higher procurement in a given period, while lower values of X lead to lower expenditure levels.

Because of the control knob effect of the parameter X upon both procurement and backorder levels, each inventory management policy was simulated using 5 different values for X. Parameter values used were: 0.1E-02, 0.1E-03, 0.1E-04, 0.1E-06, and 0.1E-08.

Since a Monte Carlo process was employed to simulate the timing of events within a quarter, observations from the RIME model are random variables. To measure the variability associated with the Monte Carlo process, two replications

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were performed for each of the five Buy Support Objectives used. That is, in simulating a given item group, a given inventory management policy was simulated twice for each of the five values of X employed; a total of 2 x 5 = 10 runs for each LRU/SRU group to be evaluated. Since we were interested in evaluating the effectiveness of 13 different inventory management policies for the control of 17 different LRU/SRU groups, a total of 10 x 13 x 17 = 2,210 data points were developed in conducting this study. In the next section, we discuss the results obtained from the simulation effort.

Chapter V

Aggregate Results

As discussed in Chapter IV, we used the RIME Simulation Model to evaluate the inventory system performance of 13 proposed rules for recoverable item inventory management. For each rule, 17 different LRU/SRU groups were simulated, and two replications were performed for each rule to measure the variability induced by the Monte Carlo procedures used to represent demand within each quarter. Of these 17 LRU/SRU groups, 13 were peculiar components of F-111 aircraft, while four are peculiar to the F-15 aircraft.

In this chapter, we discuss the performance of each rule when results for each LRU/SRU group are totaled by aircraft. Results for individual LRU/SRU groups are discussed in Chapter VI. Measures of the statistical reliability of the simulation results are also presented in Chapter VI.

Expected Long-term Results

If flying programs remained stationary, and we observed a given inventory system for a long period of time under different funding levels, we would expect to see results similar to those shown in Figure V-1. This figure displays hypothetical results for two different inventory management policies, indicated by curves #1 and #2 respectively. That is, if we were to spend a relatively small amount money during this long time period, we would expect to see a high level of back orders regardless of the inventory management rule used. On the other hand, if a large amount of money were used to buy LRU and SRU spares, we would expect to observe a much a lower back order rate. Also, we would expect to observe dimishing returns for each additional dollar invested as shown for both curves in Figure V-1. Note that for the hypothetical data shown in Figure V-1, curve #1 dominates curve #2. That is, curve #1 has a lower backorder rate than curve #2 for every possible level of expendature. Conversely, a given backorder rate may be obtained for a lower level of expenditure than for curve #2. Consequently, we say that the management policy associated with curve #1 is more "costeffective" than the policy associated with curve #2.

In our study, we expected to observe results similar to Figure V-1 for each of the inventory management policies evaluated. However, there are several reasons why we might not obtain nice smooth curves such as those shown in Figure V-1 in our four year simulation that utilizes actual D041 demand histories. First, the world is not stationary.

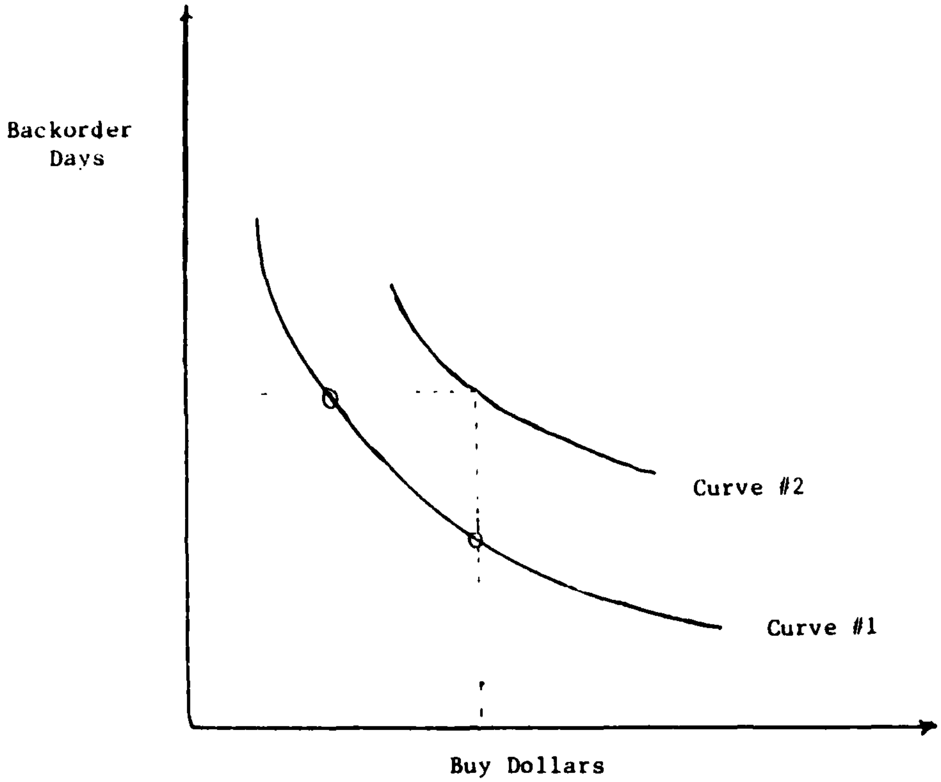


Figure V-1. Expected Long-term Relationship of Backorder-days When Demand is Stationary.

Flying programs changed significantly for both the F-15 and F-111 aircraft during the four year period from July 74 through July 80. As shown in Figure IIIl, in July 1974 only one base of F-15 aircraft was in operation. By July 1980, however, a total of eight F-15 bases were in operation, and the total flying hour program had grown significantly. In Figure III-2, we observed that the total flying hour program for the F-111 decreased slightly during the same six year period, while flying programs at individual bases fluctuated significantly from quarter to quarter during this period. Hence, non-stationarity of demand during our four year simulation period may result in support effectiveness curves which differ in those shown Figure V-1.

A second factor which may result in curves different from Figure V-1 is that our simulation period covers only a four year planning horizon. Although four years is a long time in the lives of men, it's a relatively short interval when we are dealing with complicated aeronautical equipment with procurement lead times that range from nine to 26 months. In particular, if stock level requirements computed using Initial Provisioning logic are less than those computed using Replenishment rules, from nine to 26 months of the simulation period will elapse before any benefit will be recognized in the support statistics of our simulated inventory system. Later in this section, we will see how this lead time effect can result in support effectiveness curves that are significantly different from those displayed in Figure V-1.

A final reason that the observed support effectiveness curves may differ from those shown is that the simulation process involves at least two sources of randomness. First, Monte Carlo procedures were required to simulate individual item demand within given quarters. This simulation process introduces randomness which may cause "jiggles" in the

observed support effectiveness curves. Second, the D041 quarter-by-quarter demands may also vary significantly. Actual demands for LRU and SRU components may change drasticly from quarter to quarter. This may result in temporary imbalances in the supply system which do not "even-out" over the simulation period due to the short simulation interval used.

Consequently, although we would still expect the general diminishing-returns relationship shown Figure V-1 to be observed, we would not expect the simulation results to be as smooth and well-behaved as in Figure V-1.

Analysis Stages

As noted above, for each inventory management rule evaluated, we totaled the simulation results for all LRU/SRU groups associated with a given aircraft. We then plotted the resulting support effectiveness curves to compare the relative effectiveness of these rules. These curves were developed using two distinct phases. First, the result for all 13 rules were plotted in groups of five curves each. The sets of rules which were plotted together are as follows:

PLOT SET	RULES PLOTTED
A	1, 2, 3, 4, 5
B	1, 6, 7, 8, 9
C	1, 10, 11, 12, 13

Note that rule 1, Sherbrook's METRIC model, was plotted in each Plot Set to provide a basis of comparison across all 13 inventory management rules. In all of these plots, we computed the total LRU base back order-days and associated buy dollars observed in quarters 1-8 and 1-16, respectively, and plotted the 8 and 16-quarter totals for each inventory management rule. Figure V-2 shows our results for Plot Set A. This Figure plots the results for Rules 1 thru 5 for F-111 aircraft. The graph displays LRU base backorder-days observed during the simulation runs verses the corresponding values for procurement expenditures. In the graph, dashed lines display totals for quarters 1 thru 8, while solid lines display totals for quarters 1 thru 16. There is one exception to this rule. Curves using "*" as a plot symbol are always connected by solid lines. This is due to a "bug" in the CREATE plot software. However, this should cause no problems in interpretation since the 8-quarter totals line always lies below and to the left of the 16-quarter total line.

As shown in the figure a different plot symbol is associated with each inventory management rule. The relationships among plot symbols and inventory rules are as follows:

SYMBOL	RULE
*	First Rule
+	Second Rule
.	Third Rule
=	Fourth Rule
>	Fifth Rule

This assignment of plot symbols to inventory management rules holds for all the graphs displayed in this chapter. Thus, for Plot Set A, the symbols "*", "+", ".", "=", and ">" correspond to rules 1, 2, 3, 4, and 5, respectively, while for Plot Sets B and C these symbols represent rules 1, 6, 7, 8, 9 and 1, 10, 11, 12, 13, respectively. Let us now study these curves more closely.

LRU Base Backorders verses BuyDollars for F111 Groups

Figures V-2 thru V-4 present graphs of LRU base backorderdays verses procurement expenditures for LRU/SRU Groups peculiar to F-111 aircraft. Figure V-2 presents results for the five policies in Plot Set A (rules 1, 2, 3, 4, and 5). As shown in the figure, rules one and four dominate the other curves, while rules two, three, and four represent the third, fourth, and fifth most effective policies. Rule one represents an inventory management system in which the original Sherbrooke METRIC model is used for both initial stockage and replenishment calculations, while rule four uses the same calculations with upper and lower bounds on base and depot stock levels.

Now let us consider the results for quarter one thru eight (i.e. the dashed curves). Observe that the same general relationships among the curves hold for quarters one thru eight as are observed in the curves for quarters one thru 16. Also note that most of the procurement dollars are spent in the first eight quarters for each of the rules, while approximately one half of LRU backorders observed over the 16 quarter simulation period are observed in quarters one thru eight.

Figure V-3 presents the results for LRU base backorderdays verses buy-dollars for rules 1, 6, 7, 8, and 9. As shown in the figure, rules six and seven clearly dominate the other policies in this set. Rules one and nine are the next two choices, while rule eight

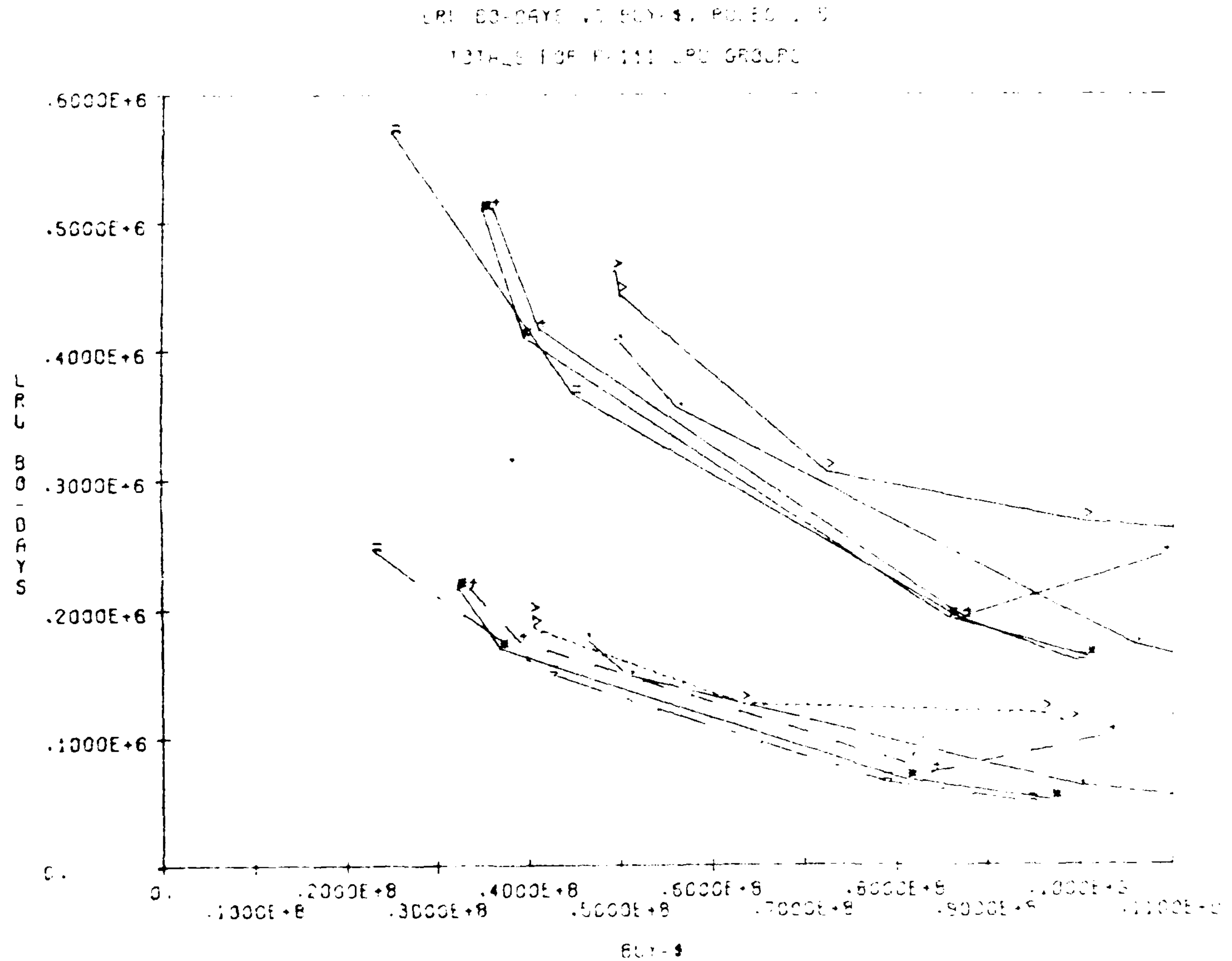
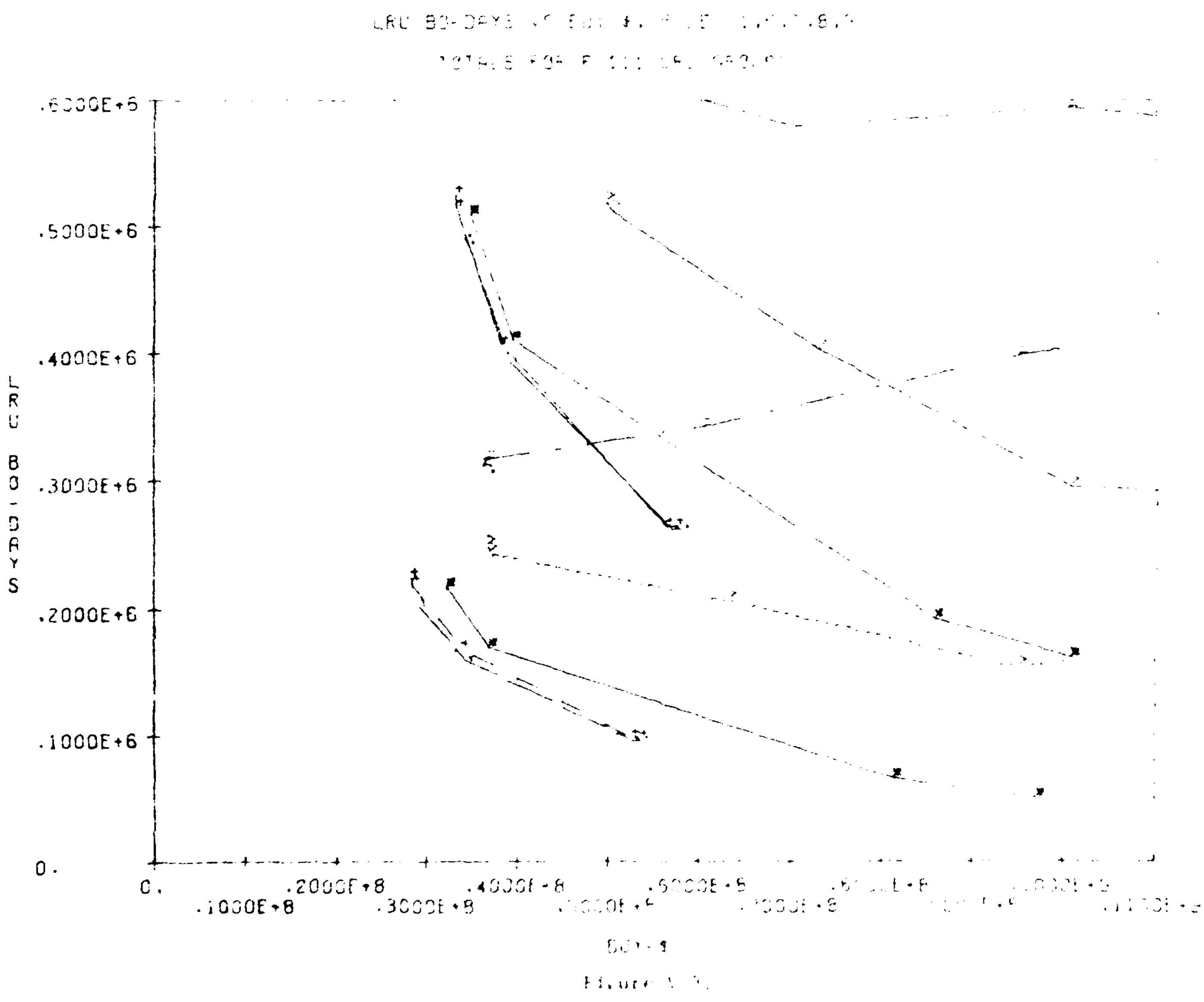

TOTALS FOR F-111 LRU GROUPS
LRU BO-DAYS
.6000E+6
.5000E+6
.4000E+6
.3000E+6
.2000E+6
.1000E+6
0.
.1000E+8
.2000E+8
.3000E+8
.4000E+8
.5000E+8
.6000E+8
.7000E+8
.8000E+8
.9000E+8
BUY-$

Figure V-2.



LRU BO-DAYS
.6000E+6
.5000E+6
.4000E+6
.3000E+6
.2000E+6
.1000E+6
0.
.1000E+8
.2000E+8
.3000E+8
.4000E+8
.6000E+8

performs very poorly. Rule six uses MOD METRIC for both initial provisioning and replenishment, while rule seven is the same policy except for upper and lower bounds on stock levels. Rule one is Sherbrooke's METRIC policy, while rule nine is a complicated calculation that uses MOD-METRIC for initial provisioning, VSL logic for replenishment buys, and METRIC logic for distribution of available assets.

In this Plot Set, the totals for quarters one thru eight show the same pattern of dominance as the totals of quarters one thru 16. Note the interesting result that for rule eight, LRU base backorders increase as the procurement dollars for quarters one thru eight increase! How can this be? How can increased expenditures result in higher base backorder levels? We believe this result is due to two major effects; these are: (A) inconsistencies between total stock requirements computed using AFLCR 57-27 and VSL computation rules, and (B) the shortness of an eight-quarter interval in comparison to the procurement lead times of the LRU/SRU groups simulated. Recall that a Buy Support Objective (BSO) is not a factor in AFLCR 57-27 computational logic. Consequently, rule eight will always produce the same set of initial provisioning levels, regardless of the BSO used. On the other hand, a Buy Support Objective is an important factor in the VSL computation. By setting the BSO to a very small value, VSL will compute a large requirement for base stock levels.

Based on the above comments, we believe that the phenomena of increasing LRU base backorders with increasing buy dollars in quarters one thru eight may be explained as follows: First, AFLCR 57-27 logic will always result in the same set of initial stock

levels. However, the VSL requirement will increase as the desired BSO increases. Consequently, very small desired BSOs will generate buy requirements as soon as the replenishment phase of the simulation begins. This will result in additional procurement expenditures. However, because of the long lead times of these items, the procured assets will not be delivered until late in the first eight quarters of the simulation, if then. This is too late to have much effect in reducing backorders observed in quarters one thru eight. Meanwhile, what is the distribution policy doing concerning LRU backorders? Recall that the current RIME simulation model utilizes a "trikle-back" distribution policy. That is, no lateral redistribution is simulated, and assets are returned to the depot only as a result of NRTS actions. Consequently, if a base finds itself in an understocked position, and the depot is out of stock, the base must wait until the depot is resupplied. The depot maybe resupplied in one or two ways; (A) the delivery of procurement assets, which have a long procurement lead time, or (B) the completion of repair of a NRTS asset. In either case, if a base develops an LRU backorder, a very long time may elapse before the depot has stock available to fill that need.

Figure V4 displays the graphs of LRU base backorderdays verses buy dollars for rules one, 10, 11, 12, and 13. As shown in the figure, rule one (METRIC) is best for middle and high values of buy-dollars, while rules 12 and 13 provide the best results for very low procurement expenditures. Rule 10 is the nextbest curve, while rule 11 performs very badly. Rule 11 uses AFLCR 57-27 logic for initial provisioning, and METRIC for replenishment buys and distribution. We believe that the inconsistency of the AFLCR 57-27 logic and the METRIC logic is the reason for the poor performance of this rule. The discussion for the poor performance of rule eight also appears to apply here.

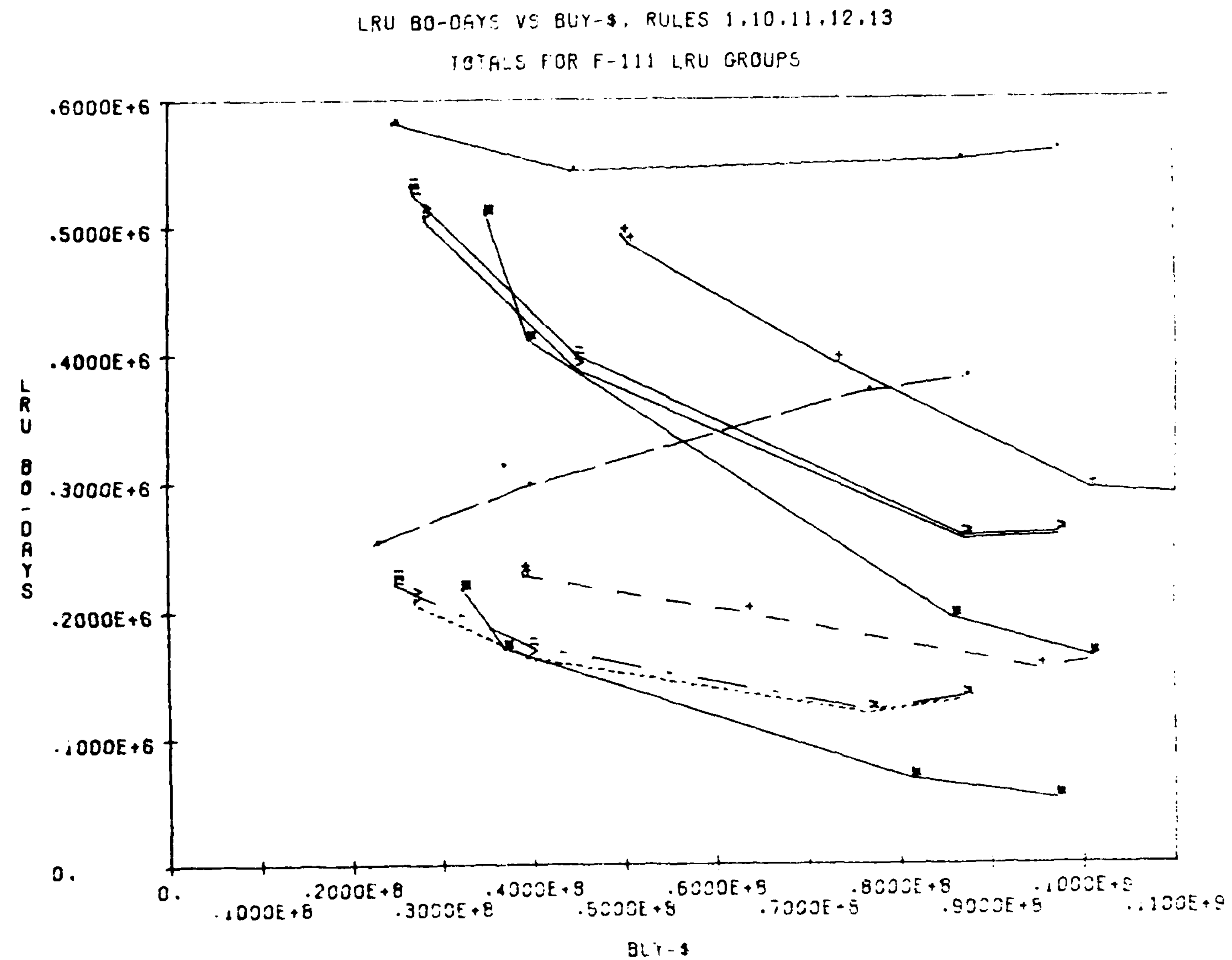

LRU BO-DAYS VS BUY-$, RULES 1,10,11,12,13
TOTALS FOR F-111 LRU GROUPS
LRU BO-DAYS
.6000E+6
.5000E+6
.4000E+6
.3000E+6
.2000E+6
.1000E+6
0.
.1000E+8
.2000E+8
.3000E+8
.4000E+8
.5000E+8
.6000E+8
.7000E+8
.8000E+8
.9000E+8
.1000E+9
.1100E+9
BUY-$

Figure V-4.

LRU Backorders vs Buy-Dollars for F-15 LRU Groups

Figures V-5 thru V-7 present graphs of LRU base backorder-days vs procurement expeditures for the inventory management rules in Plot Sets A, B, and C for LRU/SRU groups peculiar to the F-15 aircraft. In this case, there are only four LRU/SRU groups whose values are totaled, and one of these groups, Group 14, represents approximately 80% of the total procurement expenditures and base backorders for items in this family.

Figure V-5 plots observed LRU base backorder-days vs buy-dollars for rules for 1, 2, 3, 4, and 5 for the F-15 LRU groups. In this case, rule 2 (METRIC with equal bases) and rule 5 (VSL) provide the best performance. Rule 2 dominates for low buy-dollars, while rule 5 dominates for high expenditure levels. Rule 1 (METRIC) and rule 4 (METRIC with bounds) provide similar results, while rule 3 (METRIC with a cost discount) provides the worst performance with this set of five rules.

A comparison of the curves for the 8- and 16- quarter totals is interesting. Comparing these curves, observe that approxmately half of the procurement dollars over the four year simulation period is spent during the first eight quarters, while a small fraction of the total LRU base backorders observed over the four year period occur in quarters 1 through 8. This is probably due to the fact that the F-15 flying program was very low during the first 8 quarters of the simulation period, as shown in Figure III-1.

LPU BO-DAYS VS BUY-$, RULES 1-5

TOTALS FOR F-15 LRU GROUPS

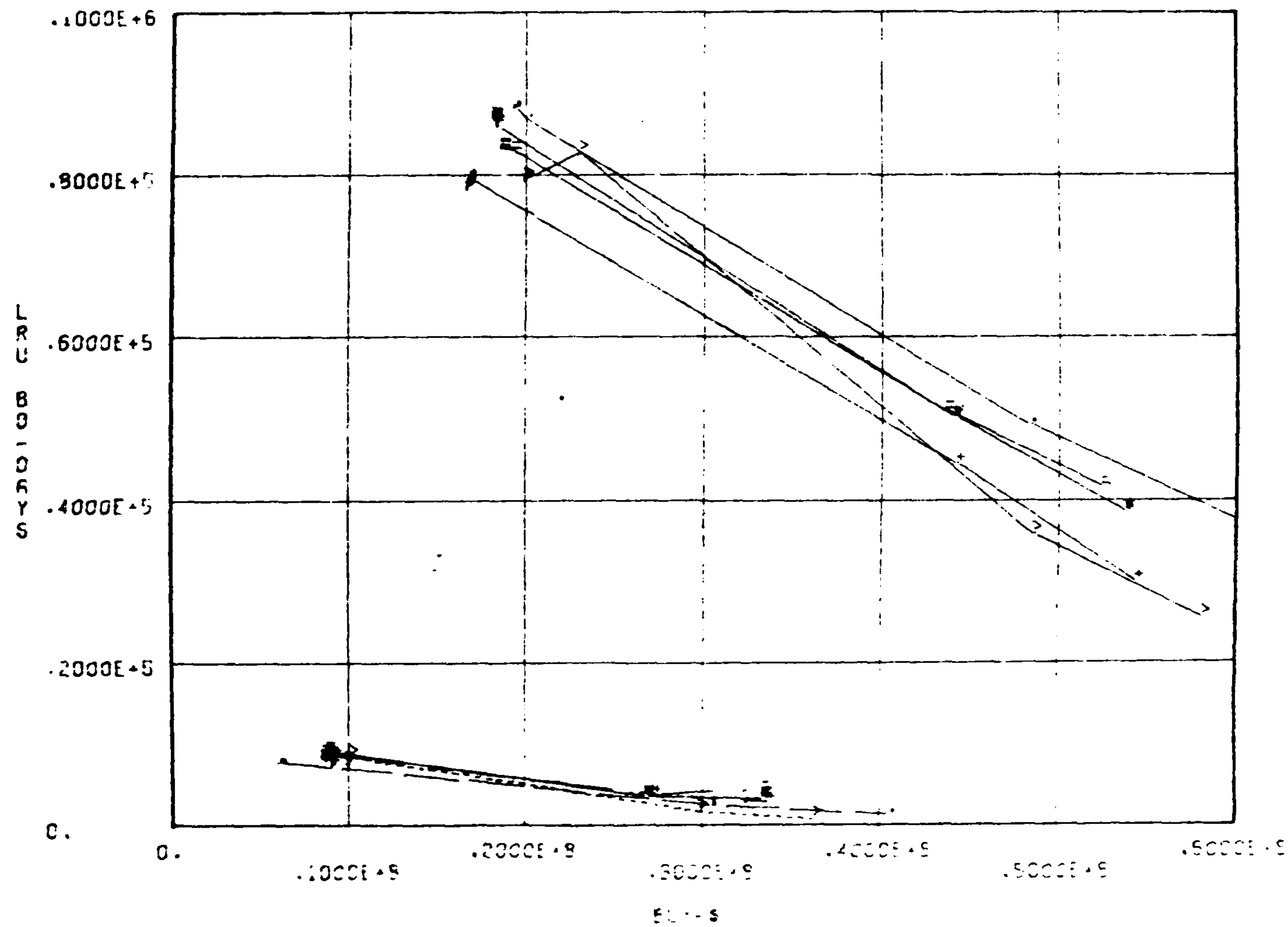


Figure V-5.

Figure V-6 graphs the LRU base backorders vs procurement expenditures for rules 1, 6, 7, 8, and 9. As may be seen from the figure, rule 6 (MOD-METRIC) clearly dominates the 16-quarter results, while rule 7 (MOD-METRIC with bounds) is a close second. Rules 1, 9 and 8 were assigned ranks of 3, 4, and 5, respectively, based on this graph. Observe that the same general relationships among the formulas also hold for the curves of quarter 1 through 8 results. Also note that rule 8 performs very badly for the F-15, as it did for the F-111.

Figure V-7 plots LRU base backorder-days vs procurement dollars for rules 1, 10, 11, 12, and 13. In this graph, rules 12 and 13 clearly dominate the 16-quarter results, with rule 1 (METRIC) a close third. Rule 10 is the next best, while rule 11 has the worst performance of the five. Rule 12 uses MOD-METRIC for initial provisioning calculations, and the METRIC model for replenishment, while rule 13 is identical to rule 12 with the exception that upper and lower bounds are used on computed stock levels.

A Second Stage of Results

Based on an analysis of the above graphs, we developed a second set of plots. This second set of plots presented totals for F-111 and F-15 groups for five curves which appeared to have superior performance based upon an analysis of the preceeding graphs. Our results are presented in Figures V-8 and V-9. Figure V-8 presents totals for the F-111 LRU groups while Figure V-9 presents similar results for the F-15.

LRU BO-DAYS VS BUY-$, RULES 1,6,7,8,9

TOTALS FOR F-15 LRU GROUPS

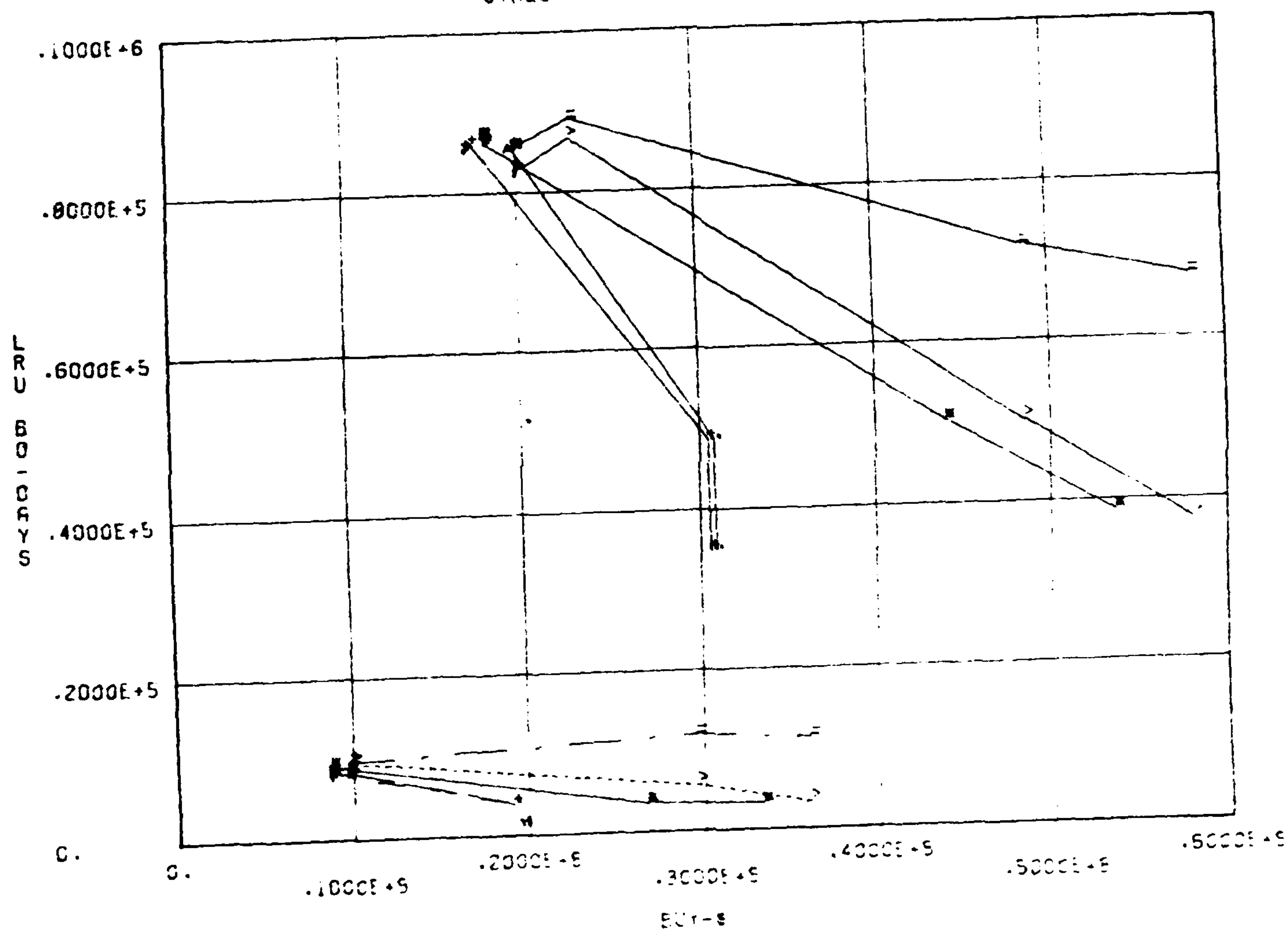


Figure V-6.

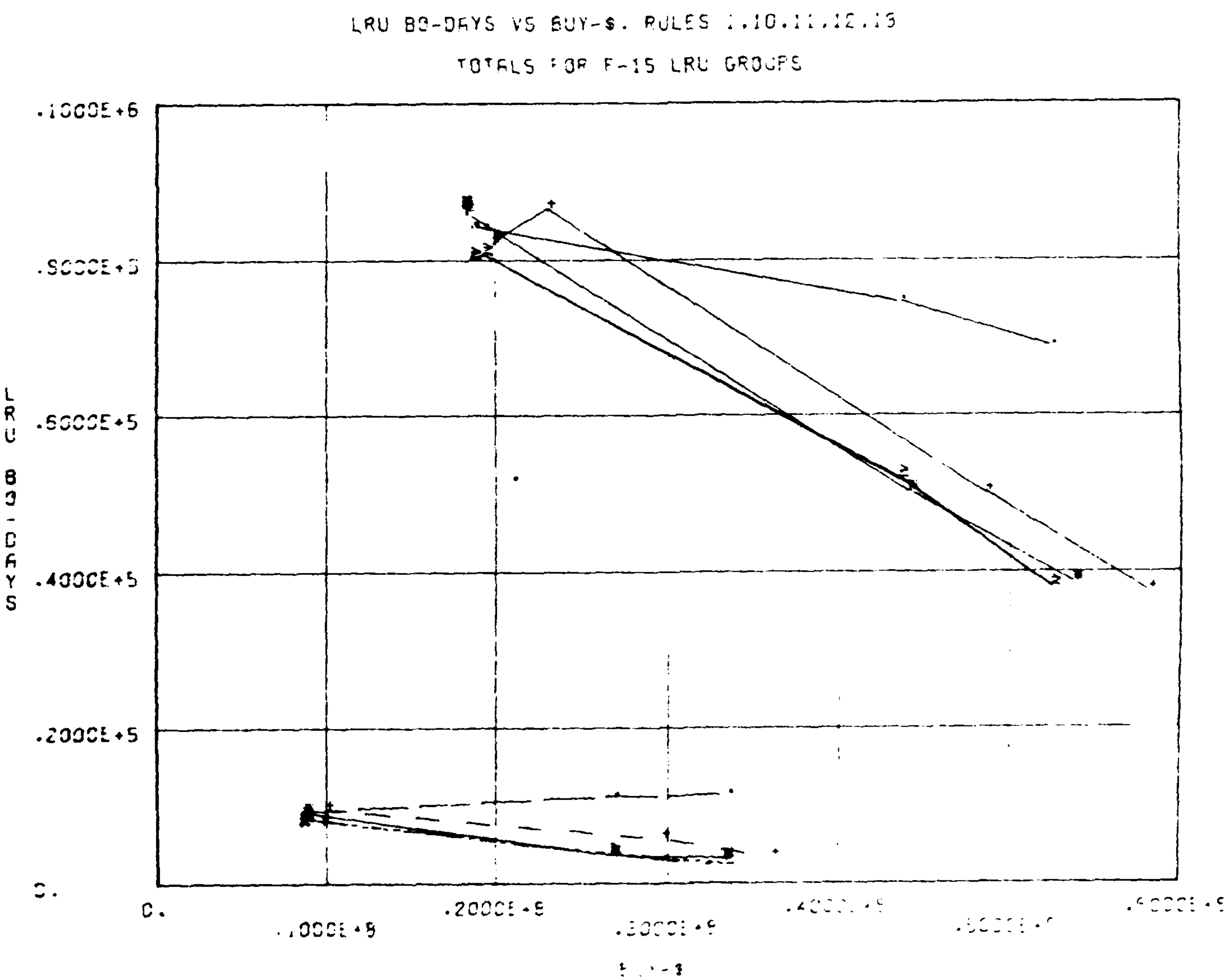

LRU B0-DAYS VS BUY-$. RULES 1.10.11.12.13
TOTALS FOR F-15 LRU GROUPS
LRU B0-DAYS
.1000E+6
.8000E+5
.6000E+5
.4000E+5
.2000E+5
0.
.1000E+9
.2000E+9
.3000E+9
.6000E+9

Figure V-7.

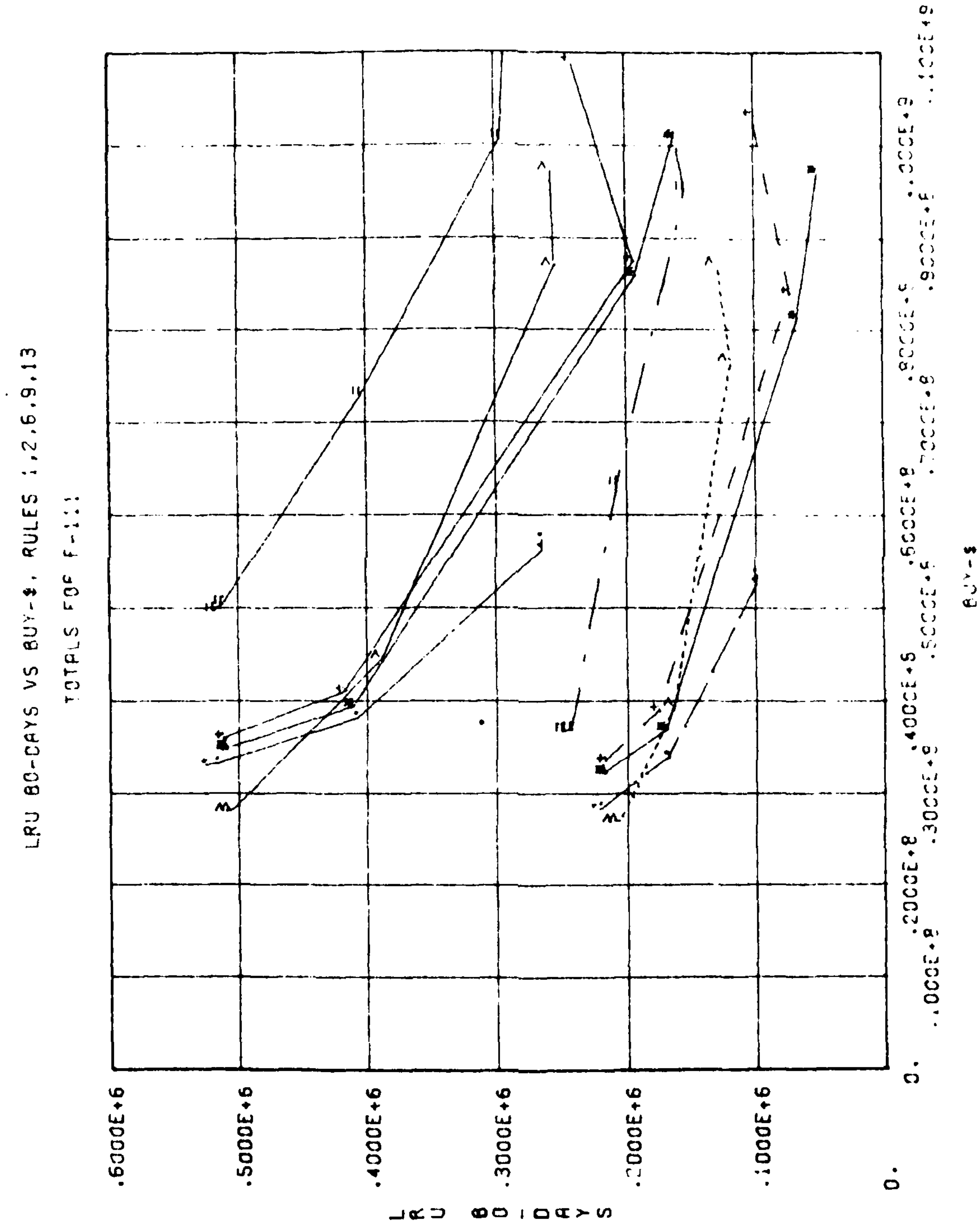

LRU BO-DAYS VS BUY-$, RULES 1,2,6,9,13
TOTALS FOR F-111
LRU BO-DAYS
.6000E+6
.5000E+6
.4000E+6
.3000E+6
.2000E+6
.1000E+6
0.
BUY-$
.1000E+8
.2000E+8
.3000E+8
.4000E+8
.5000E+8
.6000E+8
.7000E+8
.8000E+8
.9000E+8
.1000E+9
.1100E+9

Figure V-8.

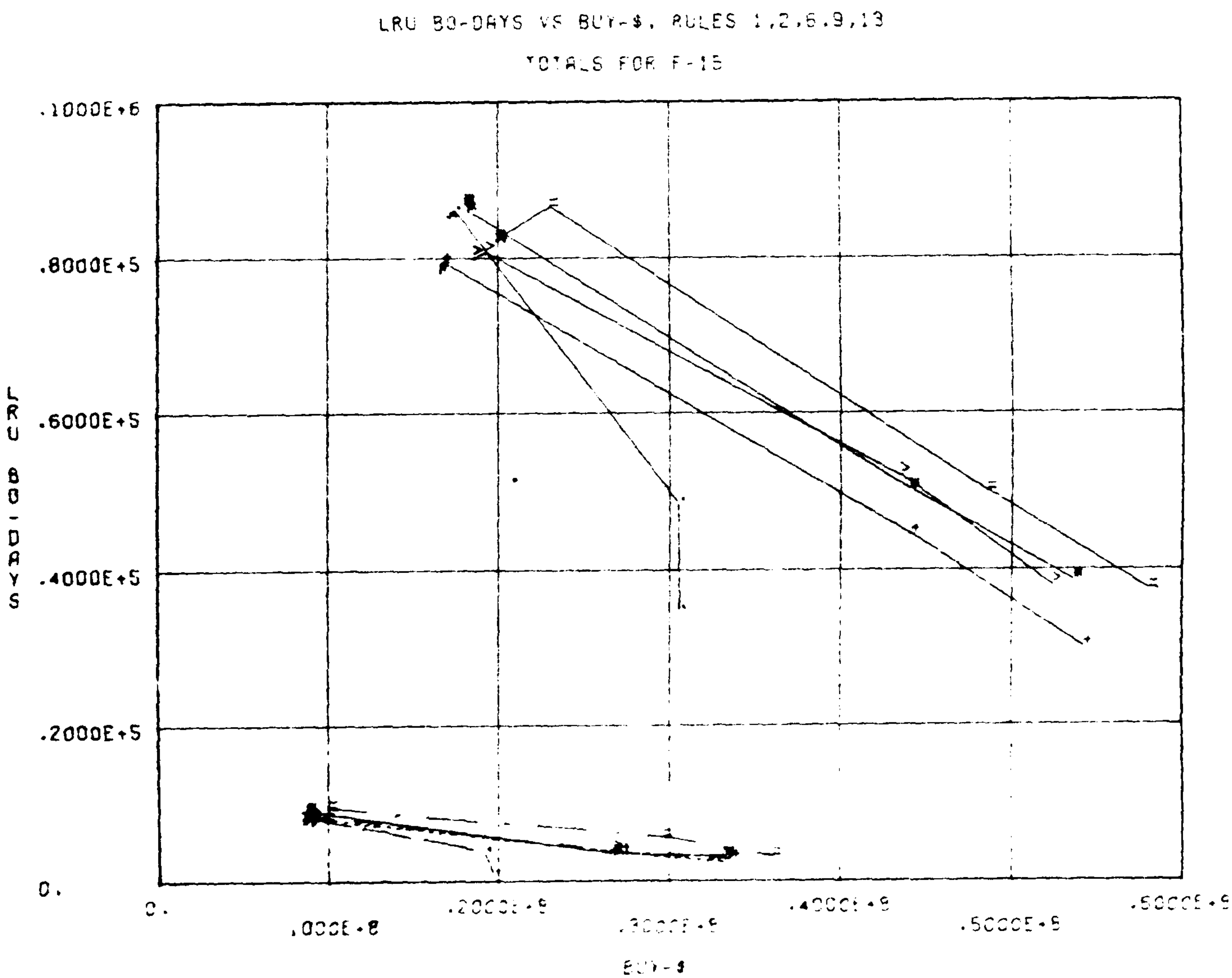

LRU BO-DAYS VS BUY-$, RULES 1,2,6,9,13
TOTALS FOR F-15
.1000E+6
.8000E+5
.6000E+5
.4000E+5
.2000E+5
0.
LRU BO-DAYS
0.
.1000E+8
.2000E+9
.3000E+9
.4000E+9
.5000E+9
.6000E+9
BUY-$

Figure V-9.

As shown in Figure V-8, rule 6 (MOD-METRIC) clearly dominates the other curves for intermediate levels of procurement expenditures, while rule 13 provides the best performance for a minimum procurement expenditure. Unfortunately the MOD-METRIC curve does not extend into the region of high procurement dollar expenditures, so we cannot tell if it continues to dominate rules in this region. In this plot, rule 9 clearly has the worst performance. Rule 9 utilizes MOD-METRIC for initial provisioning, VSL logic for replenishment buys, and METRIC logic for distribution. Once again, the 8-quarter totals display the same general relationships as curves showing totals of the 16-quarter results.

Figure V-9 plots LRU base backorder-days vs buy dollars for rules 1, 2, 6, 9, and 13 for the four peculiar F-15 LRU/SRU groups. Again, rule 6 (MOD-METRIC) dominates the middle level of expenditures, but the curve does not extend to the high procurement expenditure region. Note, however, that the observed backorders for rule 6 are almost as low for an expenditure of approximately 31 million dollars as are observed for rule 2 with an expenditure of approximately 55 million dollars. On the other hand, rule 1 (METRIC) provides better backorder performance when the minimum procurement expenditure is involved. Based on these curves, it appears that the appropriate ranking of these rules from best to worst would be rules 6, 2, 9, 1, and 13.

Again, the reader is cautioned that there are only four LRU/SRU groups associated with the F-15, and that a single group, Group 14, accounts for approximately 80% of the total back orders and expenditures associated with the F-15.

Additional Curves for F-111 and F-15 LRU Groups

In performing this study, we developed a large number of support effectiveness curves in addition to those discussed earlier in this chapter. Some of these are presented in this section. Specifically, Figures V-10 through V-14 present plots for F-111 groups of LRU fills, total requisitions filled, total backorder-days, LRU depot back-order-days, and total depot back order days for rules 1, 2, 6, 9, and 13. Figures V-15 through V-19 present similar results for F-15 LRU/SRU groups. These plots utilize the same conventions for plot symbols as presented earlier. Solid lines represent totals for quarters 1 through 16, while dashed lines represent totals for quarters 1 through 8. In general, the same patterns of dominance may be observed in fill rate statistics as were observed for LRU base backorders.

We found a major surprise in the curves presented here. In particular, we found no consistent relationship between depot level backorder days and buy dollars for any of the policies evaluated. This may be seen by inspection of Figures V-13 abd V-14 for F-111 items and Figues V-18 and V-19 for F-15 items. The curves for the F-111 are particularly erratic.

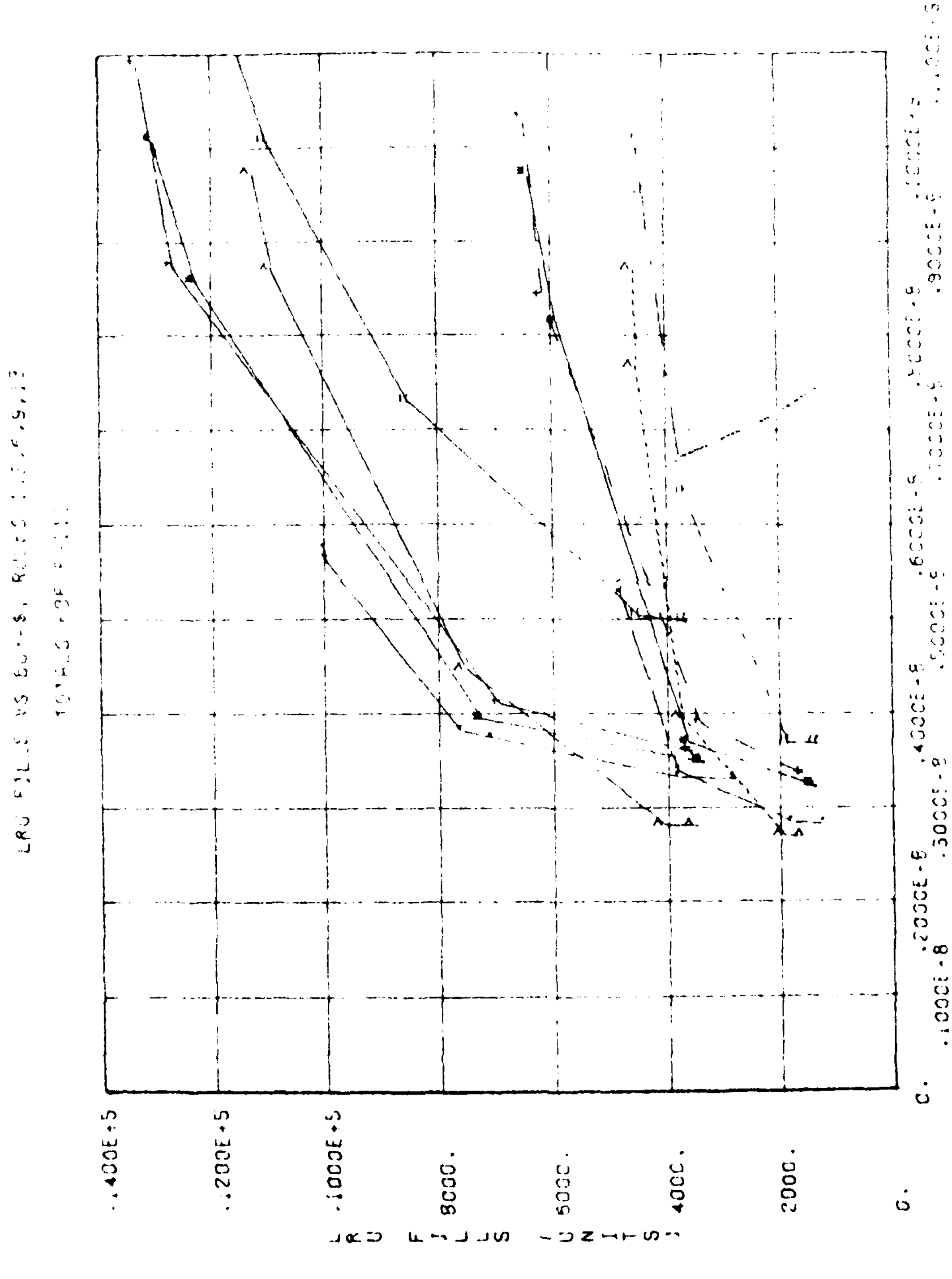

.1400E+5
.1200E+5
.1000E+5
8000.
6000.
4000.
2000.
0.
0.
.1000E-8
.2000E-8
.3000E-8
.4000E-8
.5000E-8
.6000E-8

Figure V-10.

TOTAL FILLS VS BUY-$, RULES [illegible]

[illegible]

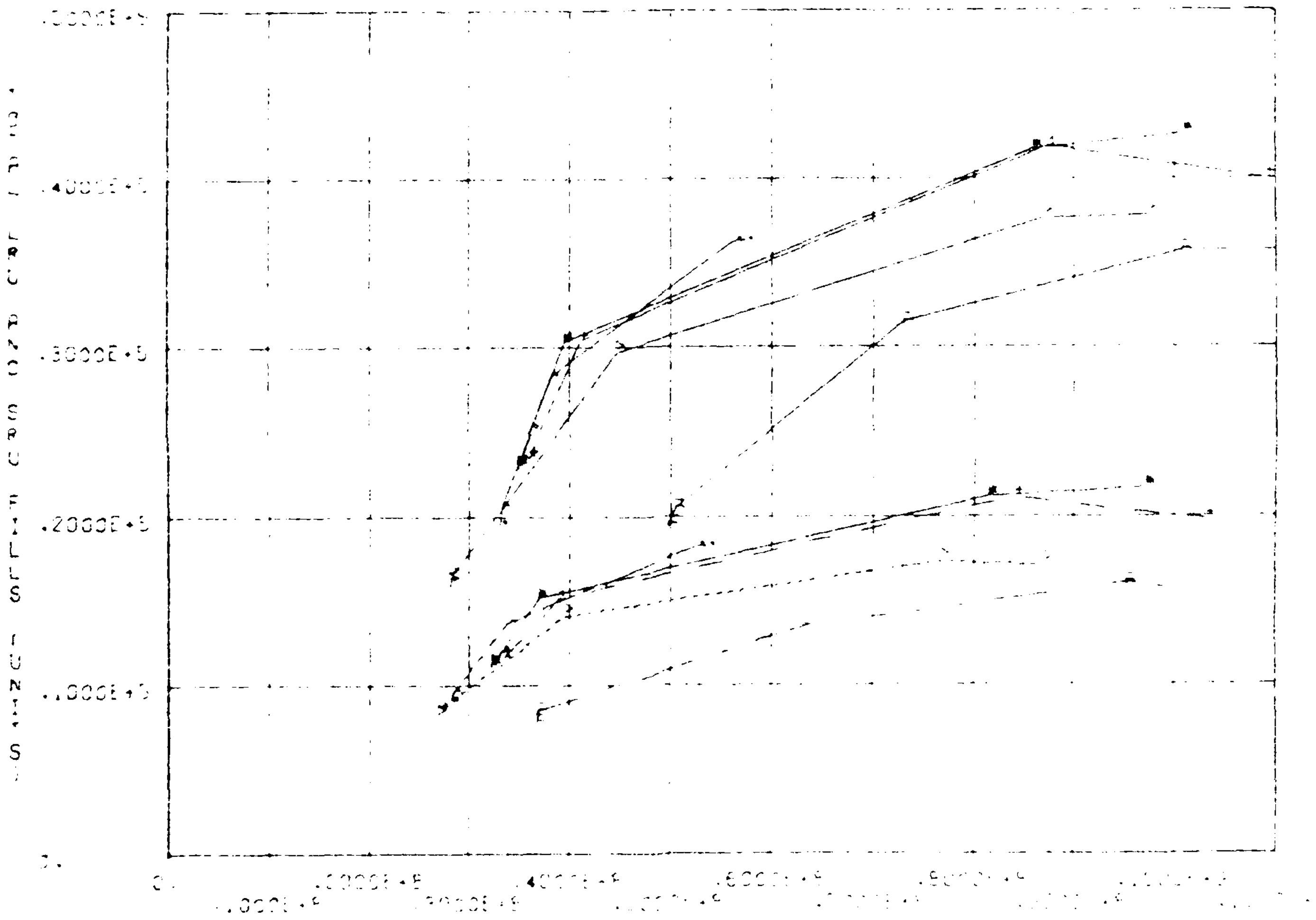


Figure V-11.

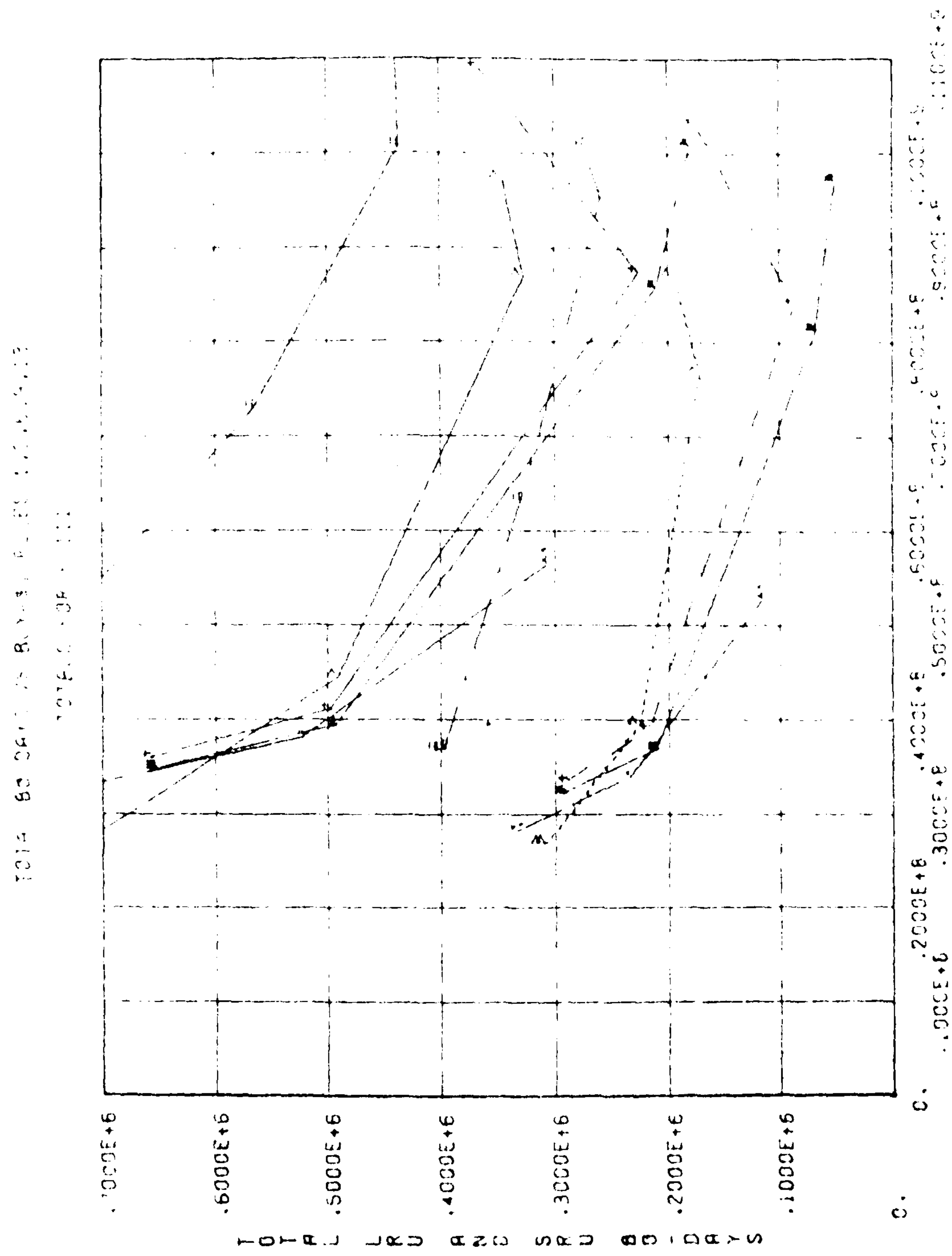

.1000E+6
.2000E+6
.3000E+6
.4000E+6
.5000E+6
.6000E+6
.2000E+6
.3000E+6
.4000E+6
.5000E+6
.6000E+6

Figure V-12.

LRU DEPOT BO-DAYS, RULES 1,2,6,9,13

TOTALS FOR F-111

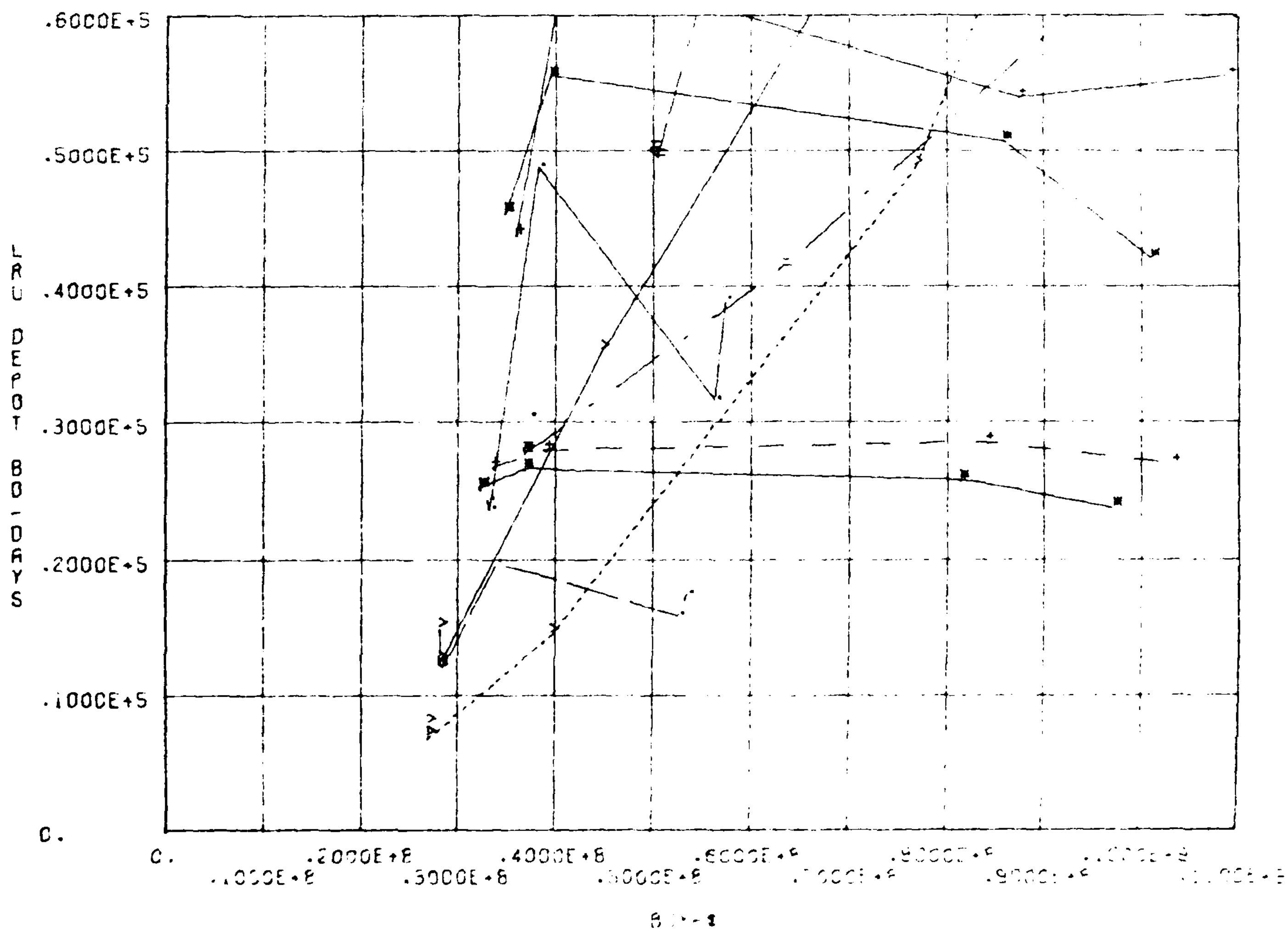


Figure V-13.

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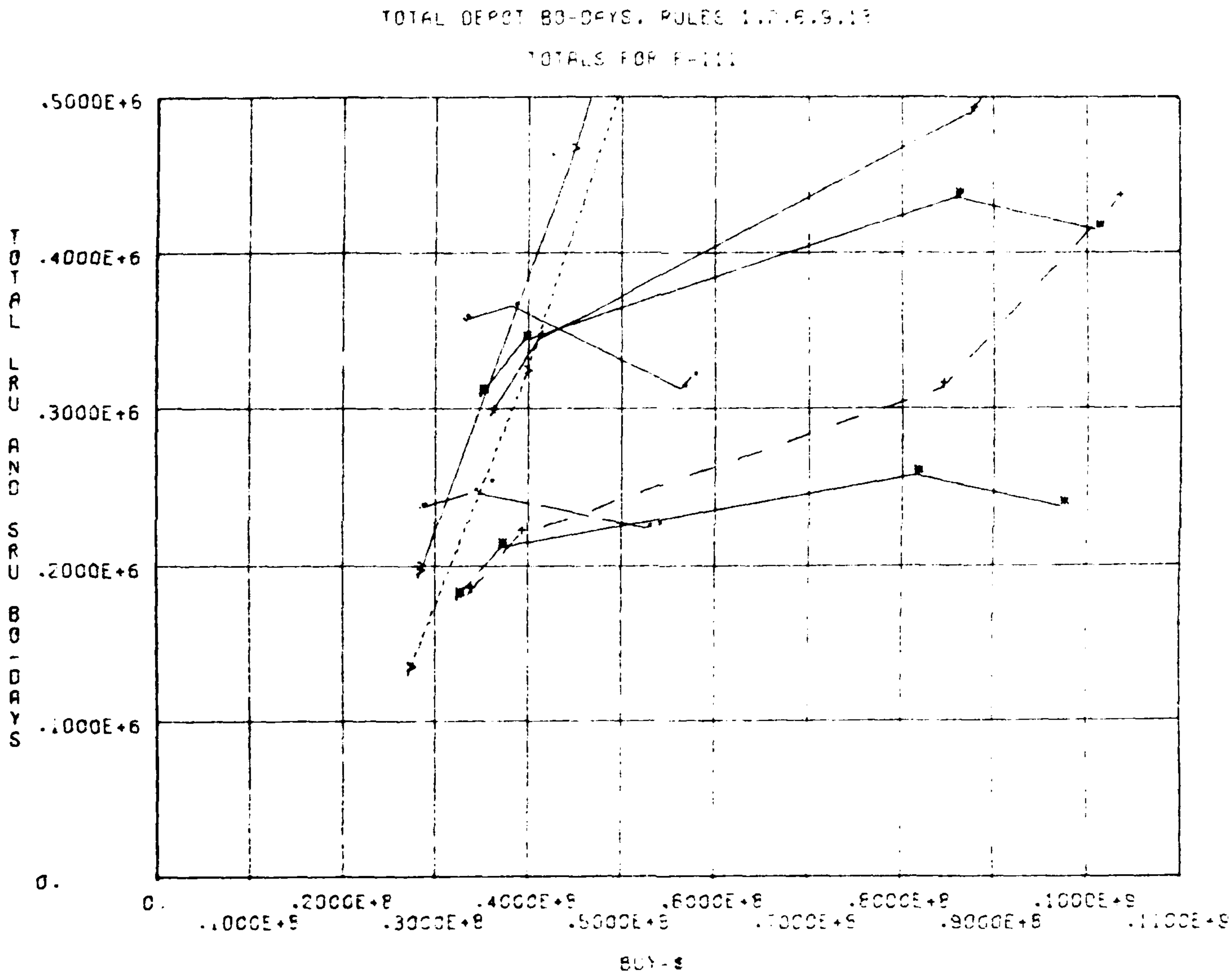
TOTAL DEPOT BO-DAYS, RULES
TOTALS FOR F-111
TOTAL LRU AND SRU BO-DAYS
.5000E+6
.4000E+6
.3000E+6
.2000E+6
.1000E+6
0.
0.
.1000E+8
.2000E+8
.3000E+8
.4000E+8
.5000E+8
.6000E+8
.7000E+8
.8000E+8
.9000E+8
.1000E+9
.1100E+9
BUY-$

Figure V-14.

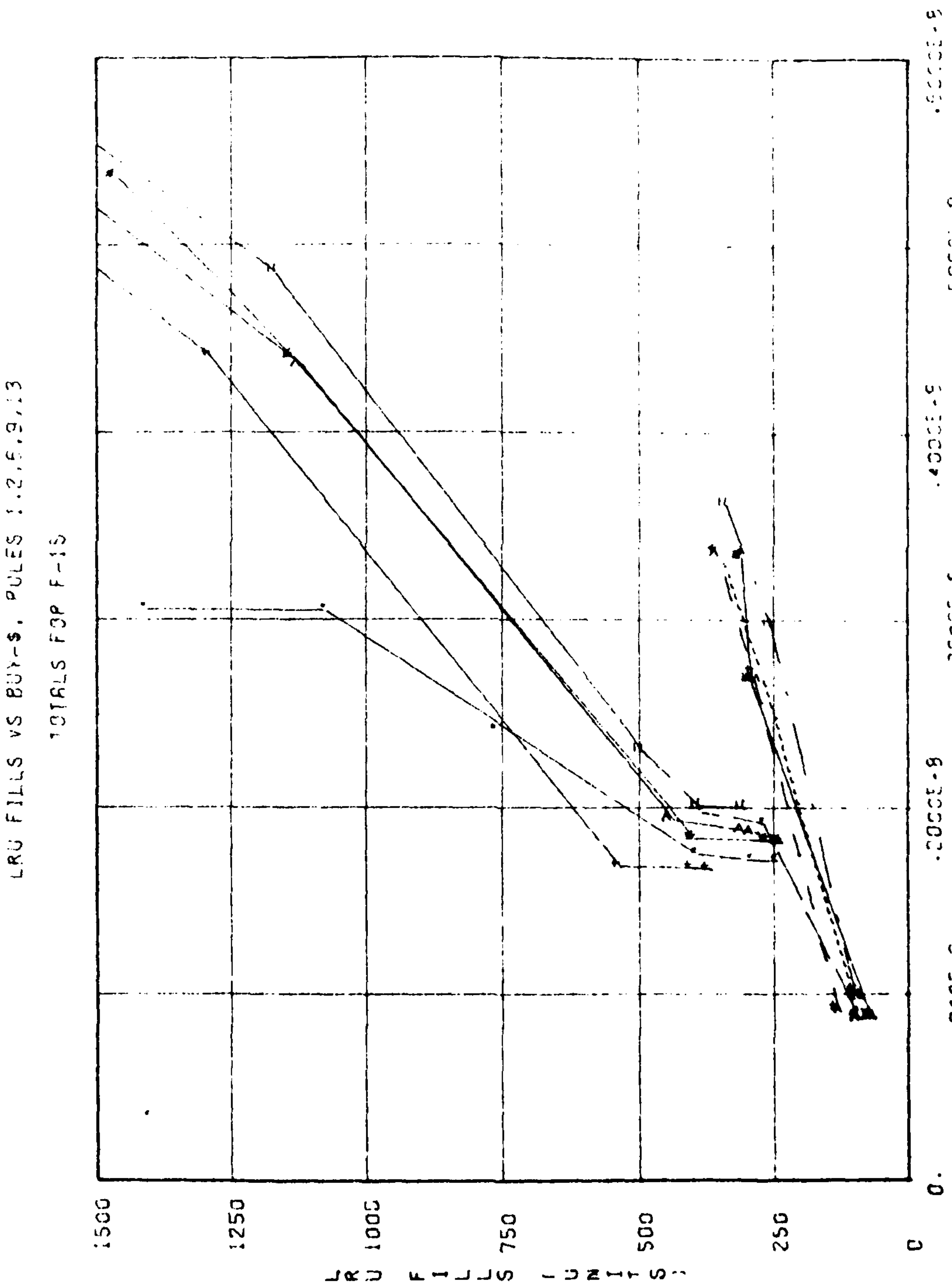
LRU FILLS VS BUY-$, RULES 1,2,6,9,13
TOTALS FOR F-15
1500
1250
1000
750
500
250
0
LRU FILLS (UNITS)
0.

Figure V-15.

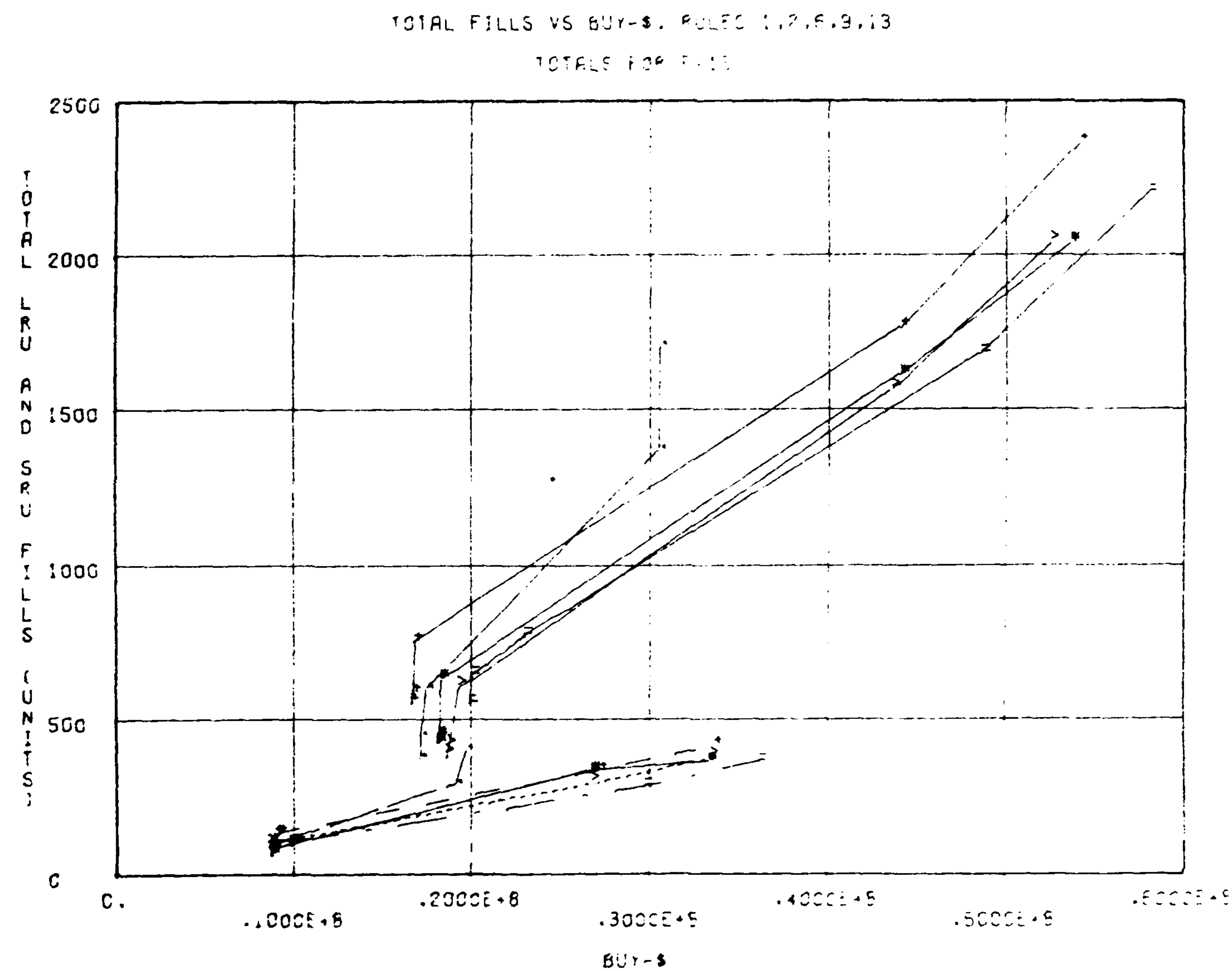
TOTAL FILLS VS BUY-$, RULES 1,2,6,9,13
2500
2000
1500
1000
500
0
TOTAL LRU AND SRU FILLS (UNITS)
0.
.1000E+8
.2000E+8
.3000E+8
.4000E+8
.5000E+8
.6000E+8
BUY-$

Figure V-16.

TOTAL BO-DAYS VS BUY-$, RULES 1,2,5,9,13

TOTALS FOR F-15

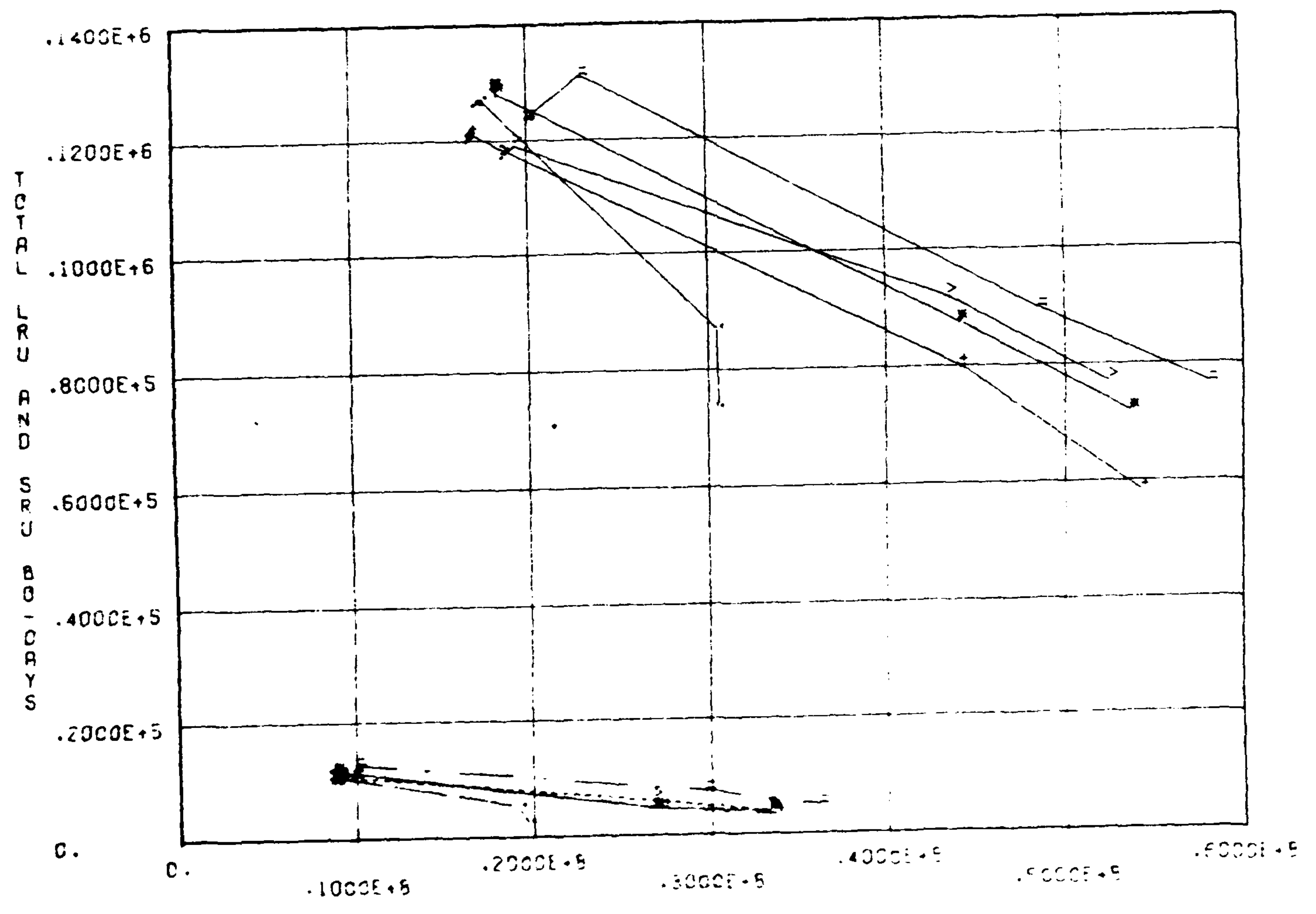

Figure V-17.

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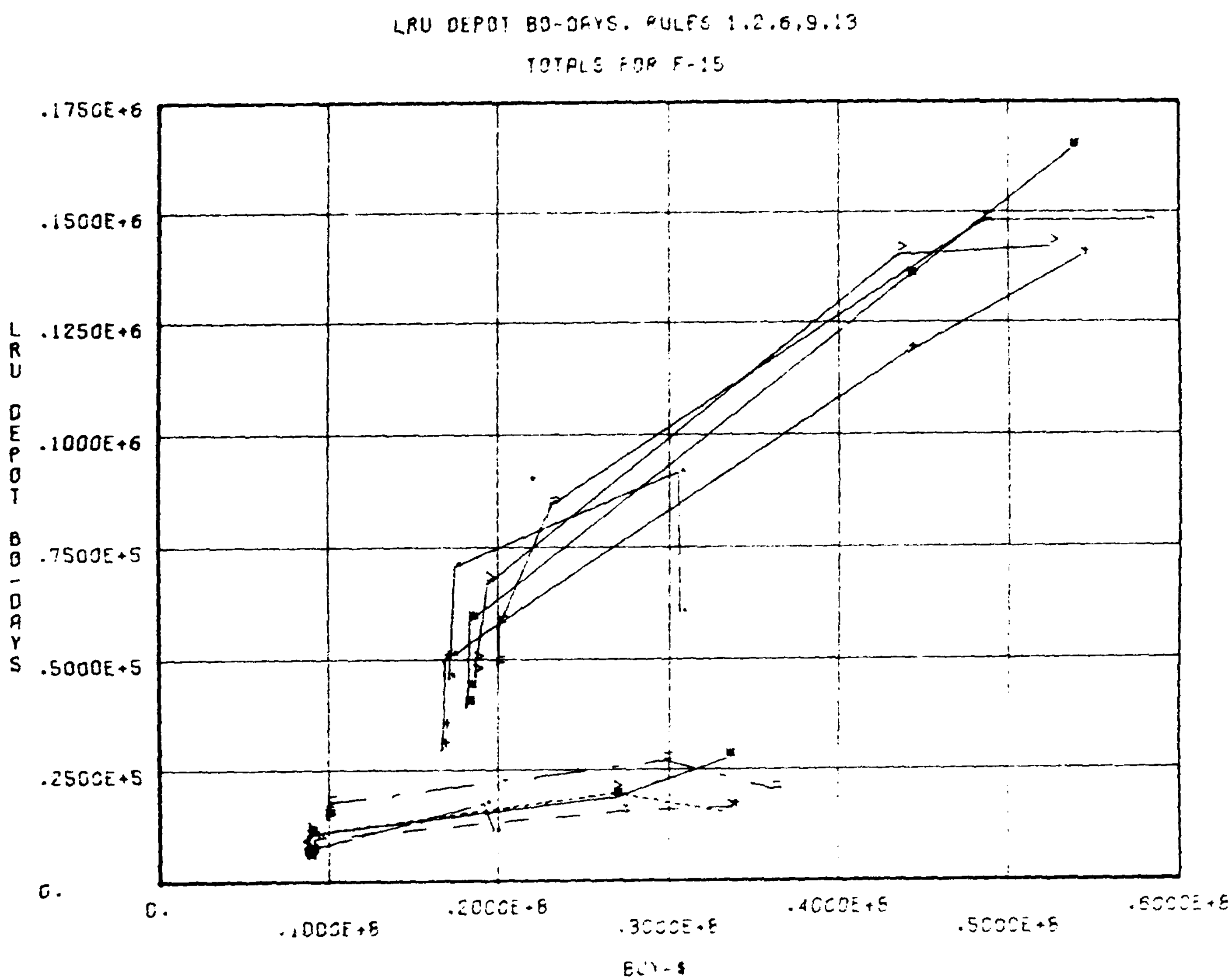
LRU DEPOT BO-DAYS. RULES 1.2.6,9.13
TOTALS FOR F-15
.1750E+6
.1500E+6
.1250E+6
.1000E+6
.7500E+5
.5000E+5
.2500E+5
0.
LRU DEPOT BO-DAYS
0.
.1000E+8
.2000E+8
.3000E+8
.4000E+8
.5000E+8
.6000E+8
BUY-$

Figure V-18.

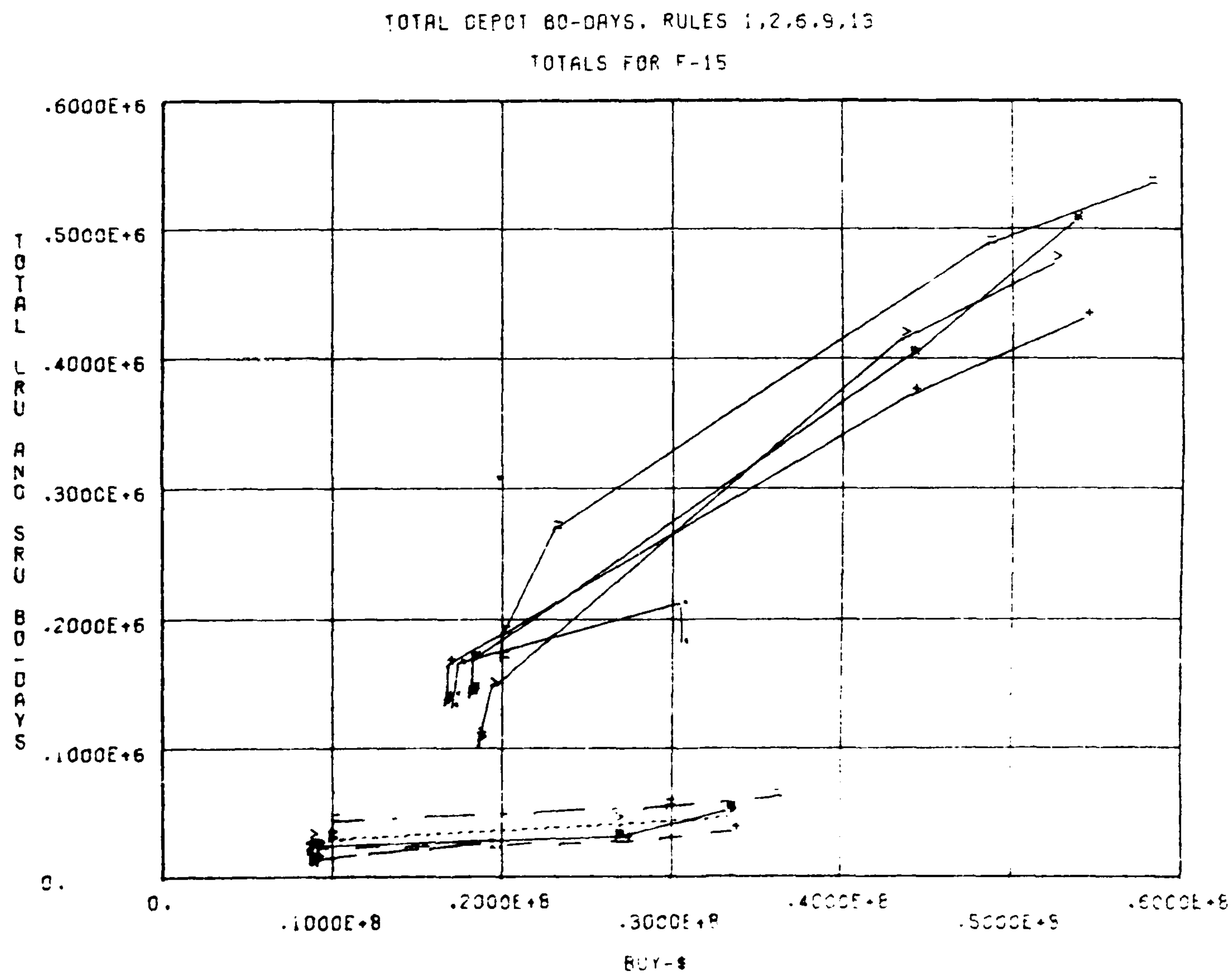
TOTAL DEPOT 80-DAYS, RULES 1,2,6,9,13
TOTALS FOR F-15
TOTAL LRU AND SRU 80-DAYS
.6000E+6
.5000E+6
.4000E+6
.3000E+6
.2000E+6
.1000E+6
0.
0.
.1000E+8
.2000E+8
.3000E+8
.4000E+8
.5000E+8
.6000E+8
BUY-$

Figure V-19.

Chapter VI

Individual LRU/SRU Group Results

and

Statistical Considerations

I. INTRODUCTION:

In Chapter III, Table III-1, we presented some of the major charateristics of RUs included in the RIME Data Set. This table indicates that the Data Set consists of a very heterogeneous collection of items. These LRUs have significantly different unit prices, failure rates, and levels of program activity. Similarly, the LRUs vary in composition from only one SRU with a total of 31 SRU base rep gens for Group 18, to a total of 33 SRUs with 3,512 SRU base rep gens for Group 9. As shown in figure VI-1, the simulation results for each of these groups also differs dramatically. Figure VI-1 shows the results from one replication of rule one, Sherbrooke's METRIC algorithm, using a desired Buy Support Objective of 1 E-02. As may be seen in the figure, the total Buy-Dollars range from $6,870 for Group 4 to $10,088,098 for Group 11. similarly, LRU base backorder days vary from a low of 215 for Group 19 to a high of 95,369 for Group 11.

Note that the groups with high levels of activity tend to dominate the totals of each of the statistics column shown in Figure VI-1. For example, Group 14 has a total of $7,635,207 procurement dollars expended in this replication out of the total of $9,032,500 expended for all groups peculiar to the F-15 Aircraft. This is 84% of

F-111 LRU Groups

LRU Group	BUY-$ LRU	BUY-$ TOTAL	DEPOT LRU	BO TOTAL	BASE LRU	FILLS TOTAL	BASE LRU	BO-DAYS TOTAL	TOTAL BUY-$	TOTAL BO
1	30750	38435	1853	1932	1368	1488	3,609	3,633	38,435	3,633
2	11596	40966	819	1234	314	443	9,656	11,330	40,966	11,330
3	94962	350939	1843	14462	5	506	27,019	30,235	350,939	30,235
4	0	6870	550	550	0	10	3,213	3,337	6,870	3,337
5	15450	18206	402	887	11	11	725	887	18,206	887
6	0	88125	79	1325	0	0	3,905	6,346	88,125	6,346
7	0	821383	774	3387	0	310	15,892	19,925	821,387	19,925
8	1035360	2433868	2945	37655	5	823	47,038	68,166	2,433,868	68,166
9	741600	1938256	1117	42666	3	2147	34,377	56,213	1,938,256	56,213
10	6887	35427	393	958	0	142	8,560	9,585	35,427	9,585
11	4194912	10088098	7356	33392	5	5681	95,369	105,522	10,088,098	105,522
12	1042730	1351584	3836	7714	4	6	450	450	1,351,584	450
13	23370	170270	778	7577	5	10	4148	10017	170,270	10,017

F-15 LRU Groups

LRU Group	BUY-$ LRU	BUY-$ TOTAL	DEPOT LRU	BO TOTAL	BASE LRU	FILLS TOTAL	BASE LRU	BO-DAYS TOTAL	TOTAL BUY-$	TOTAL BO
14	4252608	7635207	7872	52754	16	76	30954	49358	7,635,207	49,358
15	1171200	1322496	9431	12804	46	49	9351	12112	1,322,496	12,112
18	25326	31399	1772	3052	16	28	3048	3242	31,399	3,242
19	23656	43398	783	1889	39	58	215	242	43,398	242

Figure VI-1. Major Results from one replication of Rule 1, Sherbrooke's METRIC Algorithm.

the total buy dollars for the F-15. Similarly, Group 14 incurred 30,954 LRU back-order days in this replication, while the total LRU back-order days for the F-15 was 43,568. LRU backorder days. Hence, Group 14 accounted for 71% of the F-15 LRU base backorders for this replication. Similarly, group ll dominates the total buy-dollar and backorder statistics for F-111 items.

Because of the significant heterogeneity among items in the RIME Data Set, we were concerned that the aggregate curves primarily reflected the results for the small number of high activity items. Consequently, we developed detailed support effectiveness curves for each LRU/SRU group. We then analyzed the relatiive performance of each of the 13 invertory management rules for each of these groups. The results of this analysis are presented in Table VI-1.

As shown in the first line of Table VI-1, three sets of graphs were developed for LRU/SRU Group 1, with five curves on each graph. Each curve for each graph was then ranked in terms of its relative support effectiveness, where a rank of 1denoted the most cost effective, a rank of two denoted the second most - effective, and so on. As shown in the table, rule 3 was assigned a rank of one for Group 1; rule 1 was assigned the rank of two, and rules 4, 2, and 5 were assigned the ranks of 3, 4, and 5, respectively. This process was repeated for each graph, and for each LRU/SRU Group in the RIME Data Set.

The individual LRU/SRU support effectivness curves show more variability than ovserved for the curves presented in Chapter V, as expected. The individual curves often possess cross-overs no clear domincance among certain pairs of curves. Consequently, at times a significant level of judgement was required in assigned in Table VI-1 should be considered as absolute, for a different analyst may have assigned slightly different rankings in specific cases. When viewed as a whole,

TABLE VI-1

RELATIVE RANKS OF LRU BACKORDER CURVES BY LRU GROUP

LRU	RULES 1-5					RULES 1, 6, 7, 8, 9					RULES 1, 10, 11, 12, 13				
	1	2	3	4	5	1	6	7	8	9	1	10	11	12	13
PLOT SYMBOL	*	+	·	=	➤	*	+	·	=	➤	*	+	·	=	➤
F-111 GROUPS															
1	2	4	1	3	5	1	3	2	5	4	1	3	5	4	2
2	1	3	4	2	5	1	2	3	5	4	1	4	5	3	2
3	1	2	4	3	5	3	1	2	5	4	1	4	5	3	2
4	2	1	5	2	1	3	1	2	5	4	1	4	5	3	2
5	1	2	4	3	5	3	1	2	5	4	1	4	5	2	3
6	1	3	4	2	5	3	1	2	5	4	3	4	5	1	2
7	2	3	4	1	5	3	1	2	5	4	1	4	5	3	2
8	2	3	4	1	5	3	2	1	5	4	1	4	5	3	2
9	2	5	3	1	4	3	1	2	5	4	1	4	5	3	2
10	2	3	4	1	5	3	2	1	5	4	1	4	5	3	2
11	1	3	4	2	5	3	2	1	5	4	1	4	5	3	2
13	2	3	4	1	5	3	1	2	5	4	2	5	4	2	1
RANK OF F-111 TOTALS	2	3	4	1	5	3	1	2	5	4	1	4	5	3	2
F-15 GROUPS															
14	3	1	5	2	4	3	1	2	5	4	3	4	5	2	1
15	3	1	5	4	2	3	1	2	5	4	3	4	5	2	1
18	1	4	2	3	5	3	1	2	5	4	3	4	5	2	1
19	2	1	5	3	4	1	2	3	5	4	3	4	5	2	1
RANK OF F-15 TOTALS	4	1	5	3	2	3	1	2	5	4	3	4	5	2	1

NOTE: The D041 data sets for LRU Groups 12, 16, and 17 contained significant inconsistencies; consequently, these groups were not included in this analysis.

however, certain persistent patterns appear which seem to be valid general findings.

First, several combinations of rules tended to give almost identical results. For example, rules 1 and 4 -- the METRIC policy without and with bounds, respectively --often gave identical backorder versus buy-dollar curves. Similarly, rules 6 and 7 often gave identical results. These rules represent the MOD-METRIC computation without and with bounds, respectively. Finally, rules 12 and 13 often gave identical results. Rule 12 uses MOD-METRIC logic for initial provisioning, and METRIC logic of replenishment and distribution calculations. Rule 13, on the other hand, is identical to rule, 12, except for the fact that upper and lower bounds are used in the initial provisioning calculations.

Another general observation was the rules 3 and 5, 8 and 9, and 10 and 11 always performed very poorly. Rules in which the initial provisioning logic was inconsistent with replenishment logic performed particularly badly. In fact, rule 8 often produced the interesting result that increased procurement dollars was accompanied by increased base-level LRU backorders for the simulated 16 quarter time period.

So which rules are best? Figure VI-2 presents histograms of the ranks assigned in Table VI-1. Not that we have also computed the average rank for each Plot Set summarized in Figure VI-2. As shown at the top of this figure, Rule 1 (METRIC) had the lowest average rank of the five rules in Plot Set A, with an average rank of 1.58. Rule 4 (METRIC with bounds) had the second lowest average rank, while rule 2 had the third lowest rank.

In considering Plot Set B, rule 6 (MOD-METRIC) had the lowest average rank of 1.5, while rule 7 (MOD-METRIC) with bounds) had an average rank of 1.83. Rule 1,

Figure VI-2.
Distribution of Ranks within each Plot Set.

F-111

Rank	Plates 1-5					Plates 1,6,7,8,9					Plates 1,10,11,12,13				
	1	[illegible]	[illegible]	[illegible]	[illegible]	1	[illegible]	7	8	[illegible]	1	10	11	12	13
1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Average Rank	1.5?	[illegible]	3.?	1.75	[illegible]	2.11	[illegible]	1.53	5.00	[illegible]	1.35	[illegible]	4.91	2.75	[illegible]

F-15

Rank	Plates 1-5					Plates 1,6,7,8,9					Plates 1,10,11,12,13				
1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Average Rank	2.2?	1.75	4.25	1.75	3.?	[illegible]	[illegible]	2.45	5.00	4.?	[illegible]	[illegible]	5.00	2.00	1.3?

the METRIC policy with no bounds, was ranked third in this set, while rule 9 and rule 8 were always ranked 4th and 5th respectively. Rule 8 always performed badly in comparison to all of the other rules.

For rules in Plot Set C, rule 1 (METRIC) had the lowest average rank of 1.33, while rules 13 and 12 had the second and third lowest average ranks. Rules 10 and 11 were ranked fourth and fifth for most F-111 LRU/SRU groups.

When the above results are considered as a whole, it appears that the most cost effective policies observed for F-111 LRU/SRU groups are policies 6, 7, and 1, in that order.

F-15 Results

A summary of the relative ranks for the four LRU/SRU groups associated with the F-15 Aircraft are shown at the bottom of Figure VI-2. These results differ slightly from those observed for the F-111. In comparing rules 1 thru 5, rule 2 (METRIC with equal bases) has the lowest average rank of 1.75, while rule 1 (METRIC) has the second lowest rank. Rules 4 and 5 are tied, while rule 3 has the worst average rank in the set.

In reviewing results for rules 1, 6, 7, 8, and 9 for F-15 LRU/SRU groups, rule 6 (MOD-METRIC) had the lowest average rank of 1.25, while rule 7 (MOD-METRIC with bounds) was ranked second. The METRIC policy, rule 1, was ranked third, while rule 9 always performed badly, and rule 8 performed worse. Hence, rules [illegible] were assigned ranks of 4 and 5, respectively.

AD-A122 002 AN EMPIRICAL EVALUATION OF PROPOSED STOCKAGE POLICIES FOR RECOVERABLE ITEM MANAGEMENT(U) DECISION SYSTEMS DAYTON OH W S DEMMY MAY 80 TR-80-03 F33600-78-C-0524 **2/2**

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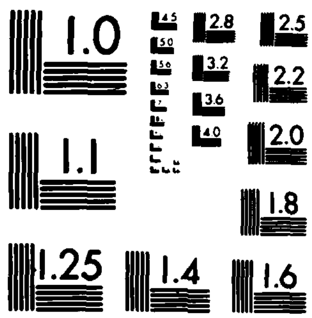

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

In the third Plot Set for F-15 groups, policy 13 was always assigned the rank of 1, while policy 12 was assigned the rank of 2. In fact, these tow policies often gave identical results. Rules 1, 10, and 11 were always assigned ranks of 3, 4, and 5 in the last Plot Set.

In reviewing the results for the F-15 groups, it is difficult to select a best policy based on this information. Rule 2 has the best performance in groups 1 thru 5, while rules 6 and 13 have the best performance for Plot Sets B and C, respectively.

Statistical Considerations

In this section, we are concerned with estimates of the statistical reliability of ur results. First, Monte Carlo procedures were used to represent the specific timing of demand within each simulation quarter. This introduces variability into our simulation results, and additional replications would result in different observed values for buy-dollars, base backorders, and other measures of inventory system performance. Consequently, we need to estimate how must our results might change if additional replications of this experiment were performed using the same set of items. Second, suppose we were to obtain another set of historical records for other LRU/SRU groups, and then repeat the simulation experiment. How much might the reults obtained in this second experiment differ from the results obtained here? Answers to this question will provide us with information concerning the usefulness of extrapolating the results obtained in this study to the general population of AFLC recoverable items.

To answer the above questions, we computed two major measures of variability. These measures are:

SIG-R = the standard deviation of total buy-dollars due to variability introduced by the Monte Carlo process, and

SIG-G = The standard deviation of total buy-dollars due to variability of individual LRU/SRU group means about the grand mean for all LRU/SRU groups.

We then normalized these values by expressing both SIG-R and SIG-G as a percentage of the total buy-dollars observed in a given simulation run. Similar calculations were also performed using LRU base backorder-days as the statistic of interest.

A sample of our results is presented in Figure VI-3. This figure presents the total values of buy-dollars and LRU backorder days for inventory management rules 1, 2, and 6. Results are presented for Buy Support Objective numbers 1, 2, and 5. Separate results were computed for both F-111 and F-15 groups. although many other similar statistics were also computed, they displayed the same pattern as illustrated in the Figure VI-3 and will not be discussed further here.

As shown in Figure VI-3, variability introduced by the Monte Carlo process provides an insignificant amount of randomness to our results. For all the values shown in Figure VI-3, the standard deviation of variability due to the Monte Carlo process never exceeded .05% of the total, and if the individual LRU group statistics are inspected, very rarely is a standard deviation of more than 1% observed. Consequently, we can conclude that if additional replications of the simulations

FIGURE -3

VARIABILITY OF BUY-DOLLARS AND LRU BASE BACKORDERS WITHIN AND BETWEEN GROUPS

F-111 RESULTS:

GROUPS 1-13		BUY - $			LRU BASE BACKORDERS		
BSO NO	RULE NO	TOTAL (1000's)	% SIG-R	% SIG-G	TOTAL (1000's)	% SIG-R	% SIG-G
1	1	17,389	.00	54.82	254.	.00	36.84
	2	17,946	.00	55.44	256.	.00	36.59
	6	16,499	.00	59.25	262.	.00	37.88
2	1	17,389	.00	54.82	254.	.00	36.84
	2	17,946	.00	55.44	256.	.00	36.59
	6	16,540	.00	59.07	257.	.00	38.90
5	1	50,468	.00	41.66	81.	.02	64.90
	2	54,531	.00	40.56	120.	.01	74.62
	6	28,664	.00	42.39	132.	.01	56.23
F-15 RESULTS: GROUPS 14, 15, 18, 19							
1	1	9,032	.00	69.71	43.	.00	55.35
2							
	2	8,313	.00	68.26	39	.01	62.65
	6	8,526	.00	70.06	42	.01	55.78
2	1	9,059	.00	69.40	43	.01	55.45
	2	8,341	.00	67.90	39	.01	62.36
	6	8,549	.00	69.78	42	.01	55.99
5	1	26,840	.00	68.11	19	.05	67.46
	2	27,121	.00	67.79	15	.05	70.74
	6	15,271	.00	67.79	17	.02	77.73

NOTE: SIG-R and SIG-G for BSOs 3 and 4 have similar values.

were performed using the same set of LRU/SRU groups, essentially identical support effectiveness curves would be obtained.

Unfortunately, high levels of variability are introduced due to group-to-group differences. As shown in Figure VI-3, the standard deviation SIG-G due to group-to-group differences generally equals from 30 to 70% of the total. As discussed earlier, there are significant differences between the different items included in our Master Data Set, and this produces significant differences in the buy-dollars and backorders observed in simulating each of these groups. Consequently, a larger sample of items will be required before we can conclude that the support effectiveness curves shown in Chapter V are representative of items in the entire population of AFLC recoverable items.

<u>The Sign Test for Differences Among Rules</u>

We may utilize data on relative ranks presented in Tables VI-1 to test for significant differences among inventory management rules within each Plot Set. For example, Table VI-2 presnts the relative rank data for rules 1, 6, and 7. In the column on the far right hand side of Table VI-2, we have placed a "+" whenever rule 7 has a higher rank than rule 6, and a minus sign otherwise. As shown, a similar calculation was performed in comparing rules 1 and 6. As shown in the Table, there were ten times out of 12 in which rule 6 had a lower rank than rule 1, and there were 8 cases out of 12 in which rule 6 was ranked lower than rule 7.

If a given pair of rules provided equal effectiveness, there would be a 50/50 chance that a given rule would be ranked higher than the other. We may use this fact to compute the probability that rule 6 would be ranked lower than rule 1 in 10 out of the 12 cases if the rules were in fact equally effective. The required

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TABLE VI-2

SIGN TEST FOR DIFFERENCES BETWEEN RULES 1 & 6, AND RULES 6 & 7

	RULE			SIGN OF DIFFERENCES	
LRU GROUP	1	6	7	1-6	7-6
F-111 GROUPS					
1	1	3	2	-	-
2	1	2	3	-	+
3	3	1	2	+	+
4	3	1	2	+	+
5	3	1	2	+	+
6	3	1	2	+	+
7	3	1	2	+	+
8	3	2	1	+	-
9	3	1	2	+	+
10	3	2	1	+	-
11	3	2	1	+	-
13	3	1	2	+	+
			TOTAL + 's	10	8
P [Total + 's ≥ x | policies are equally efficient] =				.0193	.193
F-15 GROUPS					
14	3	1	2	+	+
15	3	1	2	+	+
18	3	1	2	+	+
19	1	2	3	-	+
			TOTAL + 's	3	4
P [Total + 's ≥ x | policies are equally efficient] =				.3125	.0625

REFERENCE: Harnett, Donald L., Introduction to Statistical Methods, Addison - Wesley Publishing Company, Reading MA 1975, p. 525-527

probability is given by the binomial distribution with parameters p=.5 and N=12 trails. In this case, the probability of observing 10 or more successes out of 12 trails is .0193. That is, if rules 1 and 6 provided essentially the same performance, there is only 19 chances out of 1,000 that rule 6 would have been ranked best 10 or more times out of 12 trials. Consequently, it appears reasonable to conclude that rule 6 generally performs better than rule 6.

We may perform a similar calculation in comparin rules 6 and 7. In this case, the probability of observing 8 or more successes out of 12 equals effective. Consequently, it appears reasonable to assume that rule 6 is more cost-effective than rule 7, but the argument is not nearly as statistically strong as in the comparison in rules 1 and 6. In addition, it should be added that in several cases rules 6 and 7 performed almost identically. In such situations, the author tended to assign rule 6 a rank of 1, and rule 7 a rank of 2. This could significantly bias the results reported here.

At the bottom of Table VI-2, we present the probability of obtaining the relative rankings of curves 1, 6, and 7 observed for F-15 groups given these curves were in fact identical. Because only four groups are involved, it is difficult to make strong statements about the generality of our results for these groups.

Chapter VII

Summary and Conclusions

Objective

This paper presents the results of a simulation study to compare the relative cost effectiveness of thirteen distinct policies proposed for the management of Air Force recoverable items. The proposed policies include computations based upon the METRIC, MOD-METRIC, and Variable Safety Level (VSL) mathematical models, as well as initial provisioning rules defined in AFLCR 57-27. In addition, several proposed modifications and combinations in these methods were evaluated. Table IV-6 defines the specific details of each of the policies tested, while Chapter II provides a narrative discussion of the basic computational methods.

Data Used in this Study

We originally sought the D041 data sets for all Line Removable Units (LRUs) in F-15 and F-111 aircraft. However, none of the proposed computational methods can deal with the computation of requirements for LRUs with "common" SRUs. Consequently, we deleted from consideration all LRUs containing SRU components used in two or more LRUs. From a total of 224 LRUs associated with the F-15 and F-111, only 22 LRUs were left after the application of this editing rule. Consequently, it appears that a very large proportion of the LRUs for these aircraft contain common components.

We then obtained D041 historical data for each of the remaining LRUs and all of the associated SRU components. These data sets were then carefully analyzed. We then deleted from consideration all LRUs in which the demand histories for the LRU family were incomplete or obviously inconsistent. Five more LRUs were deleted in this step, leaving a total of 17 LRU groups with a total of 184 SRU components. Of the 17 LRUs, 13 were associated with the F-111, while 4 of the LRUs were components of the F-15. Table III-1 presents some of the major characteristics of these items.

The Simulation Model

Model Features. We then developed a simulation model for evaluating the relative cost effectiveness of the proposed inventory policies in managing each of these LRU families. The basic rules used in simulating these policies are shown in Figure IV-4. In our simulation, we wished to simulate both the initial provisioning and replenishment phases of an item's life cycle. To do this, the model assumes that initial provisioning calculations are completed sometime prior to July 1974, and that all associated initial provisioning assets are serviceable and on-hand at the individual stocking locations at the beginning of July 1974. Further, the initial provisioning stock levels are used to manage inventories for the first six months of the simulation. After that, stock levels are computed using the computational rules for the replenishment phase.

During the replenishment phase, stock levels are recomputed each six months. In performing a stock level computation, up to 8 quarters of history are used to develop moving average estimates of Mean Time Between Demands (MTBD), NRTS rates, and condemnation rates. Forecasts of installed LRU and SRU programs are set equal to be

observed D041 installed program for the LRU. This total installed program is assumed to be distributed by base in proportion to aircraft flying activity by base. Plots of the flying activity for F-15 and F-111 aircraft are presented in Figures III-1 and III-2.

During the replenishment phase, stock levels are recomputed each six months. Following a stock level computation, stocks available at each stocking location are compared to the authorized level. If a base is below its authorized level, the base submits a requisition to the depot. However, if a base is over its authorized level, no action is taken. Hence, lateral redistribution of assets is not simulated in this model. Assets only leave a base as a result of NRTS actions. Consequently, if an item is in a overstocked position, it may be some time before the assets are returned to the depot. Conversely, if a base is understocked, the base must wait until the depot ships the requisitioned assets. If the depot is out of stock, there may be long delays in filling these demands. We refer to this method of distribution as the "trickle-back" policy.

A major feature of the simulation model is that actual D041 demand histories for the period July 1974 through June 1978 are used to drive the model. That is, in simulating each of the 17 LRU families, the total number of assets in a given quarter that are base reparable generations, base condemnations, Repaired This Station (RTS), Not Repaired This Station (NRTS), depot reparable generations, depot condemnations, and overhaul condemnations are exactly the same as recorded in the D041 demand histories for these items. Monte Carlo techniques are used to determine the specific timing of these events within each quarter. The specific rules used to relate LRU and SRU reparable generations are presented in Table IV-2.

Differences from the Real World. Because of the lack of needed data, and to reduce the scope of the simulation problem to manageable dimensions, it was necessary to make several simplifying assumptions. Some of the major differences between the RIME model and "real world" Air Force systems include:

1. Stock Status Accuracy. In real world systems, stock status records never completely represent the true status of on-hand and on-order stocks. This is due to time delays in the reporting system, and the unavoidable entry of erroneous data into the information systems. In RIME, however, changes in stock status information are assumed to be known instantenously, and stock status information is assumed to be error free. This assumption would tend to make RIME results better then those antidapted in real world systems.

2. Forecast Accuracy. In real world systems, it is impossible to perfectly fortell the future. In RIME, however, we could obtain no historical forecasts of LRU installed programs. Consequently, RIME assumes that projections of LRU installed programs are always perfect, although estimates of MTBF, RTS, and condemnation factors are based upon moving average estimates. Also, because of the lack of data for periods prior to July 1974, RIME assumes that estimates for MTBF, RTS, and condemnation percentages used in initial provisioning calculations perfectly reflect the first year of activity for each simulated item. Consequently, we would expect the RIME model to produce better behavior in initial provisioning calculations than would be anticipated in real world systems.

3. Repair Times. Repair time for Air Force reparable components may vary significantly from one failed unit to the next. However, we were unable to locate any information that describes the probability distribution of repair times for Air Force reparable items. Consequently, RIME assumes that reparable item repair times are constant and equal to the standard values carried in D041 inventory management records. Again, this assumption would tend to make the RIME model performance better than that anticipated in real world systems in which repair times are variable and subject to statistical estimation error.

4. Lateral Support. As noted above, RIME assumes that a trickle-back policy is used to redistribute all reparable assets. Although this policy appears to be used in managing a large fraction of Air Force reparable items, in real world systems other methods are used if severe inventory imbalances occur. In particular, forced redistribution and other lateral support actions are often used in real world Air Force systems to adjust for NORS conditions or for other significant imbalances in the distribution of available assets. In this case, the RIME model assumptions would tend to produce worse results than would be expected in real world systems in which lateral support measures are employed.

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The Simulation Experiment

We utilized the RIME model to estimate the cost effectiveness curves associated with each of the proposed inventory management alternatives. The simulation design included individual runs for each combination of:

17 LRU/SRU groups,

13 Inventory Management Policies,

5 Funding Levels, and

2 Replications,

a total of 2,210 runs. We then developed curves of the total observed LRU base backorder-days observed versus the total procurement dollars expended over the four year simulation period. We then compared the cost effectiveness curves for each proposed policy within each LRU/SRU Group, as well as composite curves obtained by combining the curves for all LRUs in each aircraft. General findings from this analysis are presented in the next section.

General Findings

General observations from our analysis are as follows:

1. For very low funding levels, most of the proposed policies perform about the same, but there are substantial differences among the policies at middle and high dollar procurement levels.

2. Policies in which initial provisioning and replenishment calculations are based upon different computational methods all perform very badly, and policies that utilize AFLCR 57-27 logic always performed very badly. The "simplified" models which treat all bases as identical or which utilize other approximations (e.g. VSL) also performed very badly.

3. At intermediate and high procurement funding levels, policy 6--the "pure" MOD-METRIC computation--provided the best results for both F-15 and F-111 aircraft. Policy 7, which is identical to policy 6 except for the addition of upper and lower bounds on depot and base stock levels, provided results very similar to the "pure" MOD-METRIC policy. Policy 1, which uses "pure" METRIC logic for both initial provisioning and replenishment, was ranked as the third most cost effctive policy.

4. For some policies, the total backorders observed over the four-year simulation period increased with increasing Buy Support Objectives (BSO) and increasing procurement expenditures! We believe that this effect may be caused by (a) inconsistency between initial provisioning and replenishment computation rules, (b) the relatively long procurement lead times of many of the LRUs compared to the four year simulation period, and (c) the fact that the trickle-back distribution policy provides a very slow mechanism for adjusting stocks when bad imbalances of inventories exist.

5. Monte Carlo procedures were used to determine the precise timing of individual reparable generations within a simulated quarter. Statistical analysis of our results

indicate that the Monte Carlo procedures introduced very little variablity into the simulation results, and that if additional experiments were performed using the same set of items, essentially the same cost effectiveness curves may be expected.

6. We found the behavior of depot level back orders summed over the four-year simulation period to be very unpredictable for most policies. No clear relationship between high levels of support and depot level back orders was observed in our data.

7. The LRU/SRU families used in this study were a very heterogeneous group, and a small number of the 17 LRU/SRU families dominated the back-order versus buy-dollar curves. However, when the alternative policies are compared within each group, we find essentially the same results as when the aggregate curves are analyzed. Namely, the "pure" MOD-METRIC policy (policy 6) provided the most cost effective alternative for a large majority of the items, while policy 7, the bounded version of this policy, provides a very similar results.

Detailed statistics and cost effectiveness curves which support the above conclusions are presented in the Chapters V and VI.

Conclusion and Conjectures. Based upon our analysis, we believe the following statements are valid.

1. The Pure MOD-METRIC Policy is the most cost-effective technique tested. Of the policies tested, all provide very similar performance at very low funding levels. However, the "pure" MOD-METRIC computation for both initial provisioning and replenishment calculations provides the bestperformance for both aircraft. Although only 17 LRUs were in our data set, the superiority of the MOD-METRIC policy was so consistent that we have high confidence that simular results would be obtained even if the simulation experiment were repeated using a much larger data set.

2. The Common Item problem is very significant. The MOD-METRIC policy assumes that an LRU contains no common items We found that this assumption was valid for only 10% of the total number of LRUs used on F-15 and F-111 aircraft. Consequently, although the MOD-METRIC policy appears superior for LRUs with unique components, we do not know how well MOD-METRIC would perform in managing the large population of common component LRUs. In fact, the theoretical problem of how to deal with common items has not yet been resolved.

3. Current D041 Data Elements needed by MOD-METRIC are often inconsistent. To be effective in real world systems, the MOD-METRIC model requires that accurate and consistent data be available for an LRU and all of its SRUs. Of the 22 LRU/SRU families with unique components used in our study, five contained data problems so severe

as to make their use meaningless. The remaining 17 LRU/SRU groups also contained data inconsistences; however, we were able to utilize editing procedures to create "life-like" data sets which were a reasonable basis for study. This approach would not be possible in dealing with real world systems. Consequently, it appears that substantial efforts would be required to improve the quality of existing data files before the MOD-METRIC computation could be utilized with confidence.

4. MOD-METRIC provided very poor performance for complex LRUs. Although MOD-METRIC provided better performance than the other alternatives tested, this policy still produced very poor results for LRUs with 20 or more SRUs. For these complex LRUs, fill rates of 20% were the best achieved even at the highest funding levels. These fill rates are much lower than anticipated in Air Force Supply Systems, and are lower than projected by the MOD-METRIC model itself. We believe the "Trickle-Back" policy is partially responsible for this poor performance, but the implicit MOD-METRIC assumptions that (a) all input factors are known with certainty, and (b) one and only one SRU fails when an LRU fails, may also be a factor.

5. No conclusion can be made as to the cost-effectiveness of the proposed methods relative to the current Air Force inventory management procedures. Although this study evaluated several procedures proposed for implementation in the Air Force system, no comparisons with the current Air Force distribution system were made. The current Air Force System uses a "Pull" distribution system based upon individual Air Force base calculations of inventory requirements--a computational method significantly different

from any of those tested in this study. Also, the current system uses lateral support procedures to resolve severe problems of supply imbalance. Such distribution methods were not used in this study. Although the "Trickle-Back" policy for redistribution appeared to be a reasonable description of the Air Force System at the beginning of this study, our data suggests that the "Trickle-Back" method may be a major cause of the poor base level backorder performance observed. However, *this is only a conjuncture.*

Suggestions for Further Research:

It seems that in every operations research study, the answers to one set of questions suggest more questions. This study is no exception. In evaluating the performance of the 13 proposed inventory management rules, a set of important new issues were identified. These issues involve (a) Comparison of the METRIC and MOD-METRIC techniques with the current Air Force logistics system, (b) Extensions of MOD-METRIC to deal with the common item problem, (c) studies of the significance of data errors and MOD-METRIC's sensitivity to them, and (b) studies to improve the computational characteristics of the MOD-METRIC computer codes. Let us now consider each of these areas in more detail.

1. Comparison with Current Methods. We found the "pure" MOD-METRIC and METRIC policies to be very cost effective relative to the other 11 policies evaluated. However, no comparisons of these methods with the current Air Force procedure was done since a significant level of programming effort is required to model these techniques. Before implementing either MOD-METRIC or METRIC methods -- or any other method, for that matter -- we believe it is desireable to evaluate the improvement expected from these methods relative to the current Air Force procedures. To do this, the RIME evaluation system must be extended to permit simulation of lateral support procedures and decentralization stock level computations. The revised RIME model might then be

used to compare current Air Force with the MOD-METRIC and METRIC procedures. In doing this, particular attention should be devoted to the determination of causes for the extremely low fill rates that were observed for LRUs with a large number of SRU components. Is the "trickle-back" redistribution policy responsible? Is the problem due to multiple SRU failures within a single LRU reparable generation? Or are there other causes for these low fill rates? Additional research is needed to answer these questions.

METRIC and MOD-METRIC Model Extensions. The MOD-METRIC model assumes that an LRU consists of unique SRU components --that is, a given SRU is assumed to be related to one and only one LRU. We found that a large proportion of Air Force reparable LRUs contain common items. Additional research is needed to quantify the nature and scope of the common item problem. In addition, research is needed to develop techniques for modeling and optimizing requirements policies and inventory levels in these situations. Alternately, if optimization problem appears too difficult, studies should be conducted to evalute the relative effectiveness of heuristic methods for dealing with the common item problem.

Data Consistency and Model Sensitivity. A major underlying assumption of MOD-METRIC is that all parameters for an LRU and its associated SRUs are accurate, consistent, and known with certainty. We found significant inconsistencies among the

data sets collected for this study, and we also believe it is impossible to design an error free real world information system. Consequently, research is needed to determine the sensitivity of the MOD-METRIC model to errors in input data. If MOD-METRIC is insensitive to certain types of data errors, little effort should be extended in correcting those errors. On the other hand, if it is highly sensitive to data errors it may never be practical to use this model in the management of real world systems. Second, additional research is needed to quantify the extent and significance of errors in current Air Force data systems and to identify the level of effort required to correct these problems. The goal here is to determine what must be done if Air Force data is to be used in a routine matter for the management of Air Force recoverable items under the MOD-METRIC methodology.

Improvement in MOD-METRIC Computation Times. We found the current MOD-METRIC computer codes required very large computer run times to perform stock level computations. For example, to compute stock levels at eight different points in time for LRUs with 20 or more SRUs required from one to two CPU hours on the Honeywell 6000 computing system. Further, computation times for LRUs with smaller numbers of SRUs generally required from .2 to .8 CPU hours per LRU family for eight levels computations. We believe that such run times are impractical for the management of the hundreds of LRUs in the Air Force inventory. Consequently, additional research is needed to find faster ways of optimizing the MOD-METRIC model.

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